BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART VII. COOK PLANT PREOPERATIONAL STUDIES 1970

John C. Ayers
Dean E. Arnold
Robert F. Anderson
H. K. Soo

Under Contract with:

American Electric Power Service Corporation
Indiana and Michigan Electric Company

Special Report No. 44
of the
Great Lakes Research Division
The University of Michigan
Ann Arbor, Michigan

March 1971

INTRODUCTION

This interim report presents the narratives and results of part of our ongoing research. It lays the groundwork for subsequent reporting of Cook Plant detailed biological surveys assembling and presenting all the earlier biological studies. Lastly, it reorganizes the format of our research reporting by making a needed separation of preoperational surveys specifically related to the Cook Plant from our studies of existing warm-water discharges.

The reporting format here being introduced is as follows:

A. COOK PLANT PREOPERATIONAL STUDIES

- A.1 Recording of Local Water Temperatures
- A.2 Study of Floating Algae and Bacteria
- A.3 Development of a Monitor for Phytoplankton
- A.4 Study of Attached Algae
- A.5 Study of Zooplankton
- A.6 Study of Aquatic Macrophytes
- A.7 Study of Benthic Organisms
- A.8 Study of the Local Fishes
- A.9 Support of Aerial Scanning

B. SURVEYS OF EXISTING WARM WATER PLUMES

C. THE ICE BARRIER AT THE COOK PLANT SITE

D. EFFECTS OF EXISTING THERMAL DISCHARGES ON LOCAL ICE BARRIERS

E. EFFECTS OF RADIOACTIVE WASTES IN THE AQUATIC ENVIRONMENT

- E.1 Gamma Scan of Bottom Sediments
- E.2 The Most Sensitive Organism for Concentration of Radwastes
- E.3 Study of Lake Michigan's Present Radioactivity Content

It is planned to follow this format more or less closely in the future. There will not always be results to be reported under each of the above headings, but all will be accounted for in each subsequent report. Sections B, C, and D will develop subheadings if such are adjudged desirable.

A. COOK PLANT PREOPERATIONAL STUDIES

A.1 Recording of Local Water Temperatures

A lake-water temperature sensing and recording system at the Cook Plant site was activated on 11 May 1970. The system consists of a thermistor-equipped submarine cable extending into the lake from the water line near the north edge of the site property; the shore end of the cable connects to a multipoint recorder.

Two of the five thermistors are located approximately 300 feet from shore; the remaining three are at about 2,500 feet offshore. The spring, summer and fall configuration of the thermistors is that they are held by subsurface floats at water depths of 2 and 4 feet at the 300-foot position, and at depths of 2, 12, and 17 feet at the 2,500-foot location.

For the winter ice season, it had been intended to remove the sub-surface floats and allow the thermistors to lay on the bottom. However, adverse weather prevented this, and the assemblies were left in the summer configuration. During the winter, part of the circuits were broken, as shown by the recordings of the various points; but part of them continued to function. However, the location of the surviving sensors is not known.

Daily maximum and minimum temperatures originating from each thermistor as well as from the water plants at St. Joseph and Benton Harbor, Mich., have been assembled by Indiana and Michigan personnel. The St. Joseph intake is at 1,490 feet from shore in 19 feet of depth. Benton Harbor's intake is at 3,375 feet and in 40 feet of depth.

The temperature data so far collected are given in Table 1.

TABLE 1. Daily maximum and minimum Lake Michigan water temperatures at the Cook Plant site and at the Benton Harbor (BH) and St. Joseph (SJ) water plant intakes. Whole degrees Fahrenheit.

	Cook Plant										BH		SJ	
Offshore	300'				2,500'						3,375'		1,490'	
Depth	2'		4'		2'		12'		17'		40'		19'	
Date														
5/11/70	57°	55°	58°	55°	54°	52°	55°	53°	54°	52°	52°	51°	54°	52°
12	57	54	57	55	54	52	55	53	54	52	52	52	53	52
13	55	53	57	54	54	51	54	52	53	51	53	52	53	49
14	53	50	54	51	52	49	52	49	51	49	52	50	49	47
15	55	50	56	50	52	50	52	50	52	50	51	50	49	47
16	57	53	56	53	53	52	53	52	53	51	52	51	51	49
17	56	52	55	52	53	51	55	52	53	51	53	51	51	50
18	57	51	56	51	54	51	55	51	54	50	53	51	53	50
19	60	55	60	55	56	54	58	54	56	54	55	53	54	53
20	60	56	60	56	57	55	58	55	56	55	54	53	54	53
21	65	56	66	56	60	55	63	56	58	55	55	53	58	53
22	65	62	65	62	62	57	63	60	62	56	57	55	60	56
23	63	60	63	61	61	56	61	57	59	56	56	53	57	53
24	64	57	64	58	61	56	63	57	60	55	56	52	58	52
25	64	61	64	61	60	60	60	60	60	58	60	56	59	57
26	63	60	63	60	61	58	61	59	60	57	61	59	59	56
27	61	55	61	55	59	57	59	56	59	55	58	56	56	53
28	56	54	56	54	56	54	56	54	55	53	55	51	53	52
29	58	54	58	54	57	55	57	55	55	53	54	51	54	52
30	61	57	61	57	59	57	59	57	59	57	57	55	57	54
31	63	60	63	60	60	58	60	59	60	58	58	57	58	56
6/1	62	61	62	61	60	59	60	59	60	60	59	58	59	58
2	62	60	62	61	60	60	61	60	60	60	60	58	60	58
3	60	49	61	49	60	46	60	48	60	46	60	46	60	51
4	50	47	50	47	50	46	52	48	49	45	48	46	51	48
5	50	46	50	46	49	45	51	45	47	45	46	46	48	44
6	60	50	60	50	56	50	58	48	55	46	47	46	46	44
7	64	59	64	58	63	56	63	56	61	56	54	46	58	46
8	68	62	69	62	64	62	65	62	63	60	60	54	61	58
9	70	65	70	65	66	64	67	64	64	63	64	60	63	62
10	70	67	70	67	67	65	68	65	66	65	65	60	65	63
11	72	67	71	67	68	66	68	66	67	65	66	63	65	64
12	70	67	71	67	68	65	68	67	67	65	66	64	66	63
13	69	65	69	65	68	65	69	66	67	58	65	56	65	63
14	69	61	69	60	67	63	67	63	67	56	63	53	65	62
15	69	67	69	67	68	67	68	67	67	64	65	55	65	63
16	70	67	69	67	68	66	68	67	67	63	62	56	67	64
17	72	70	72	70	69	68	70	68	68	68	67	65	68	66
18	74	70	74	70	70	68	70	68	69	68	67	66	67	66
19	70	67	70	67	69	67	69	67	68	66	67	62	69	64
20	67	66	67	66	67	66	67	66	66	66	65	62	64	64
21	66	48	66	48	66	45	66	47	66	45	65	48	64	48
22	65	51	65	53	62	52	63	57	61	47	50	47	56	48
23	72	61	72	61	65	57	70	62	65	52	57	49	64	54

	Cook Plant										BH		SJ	
Offshore	300'				2,500'						3,375'		1,490'	
Depth	2'		4'		2'		12'		17'		40'		19'	
Date														
6/24/70	68°	67°	68°	67°	68°	63°	70°	66°	66°	63°	66°	58°	66°	63°
25	67	50	67	50	65	46	67	52	63	45	66	46	66	48
26	53	47	53	47	49	45	52	46	47	44	47	46	48	46
27	56	48	56	48	58	47	59	47	54	47	48	46	48	45
28	66	45	66	45	62	56	63	57	60	54	51	48	60	48
29	68	63	68	63	65	61	65	61	65	61	61	52	62	58
30	71	67	70	67	68	65	68	65	67	65	64	61	64	61
7/1	73	70	73	70	70	66	71	67	70	66	67	63	67	64
2	76	71	75	71	71	68	73	69	69	68	67	66	68	67
3	76	73	76	73	73	70	73	70	73	70	69	67	69	68
4	74	70	74	70	72	70	72	70	72	70	69	68	71	68
5	72	67	72	67	70	66	70	67	70	66	68	65	68	65
6	72	66	72	66	71	66	71	67	70	66	67	65	67	65
7	75	70	75	70	72	70	72	70	72	69	70	66	67	66
8	74	72	74	72	73	71	73	71	72	71	69	68	69	68
9	72	70	72	70	70	68	71	69	71	67	69	67	68	66
10	72	70	72	70	70	68	70	69	70	68	67	64	66	65
11	71	69	71	69	70	69	70	69	70	68	68	66	67	65
12	76	69	76	69	71	69	75	69	69	68	66	65	66	65
13	79	71	79	71	76	69	76	72	75	68	68	65	74	65
14	78	76	78	76	76	75	76	75	76	74	72	66	74	72
15	77	75	77	75	75	75	75	75	75	75	72	71	74	73
16	79	75	79	75	75	74	77	75	75	73	72	71	74	72
17	79	76	79	76	76	75	77	75	75	73	72	71	74	73
18	77	73	77	73	75	72	76	73	75	71	73	72	74	72
19	76	73	75	73	74	72	72	72	72	72	72	70	72	71
20	73	65	74	66	72	45	72	48	72	45	72	54	71	47
21	70	64	70	64	71	45	71	53	71	45	62	47	64	45
22	70	69	70	69	70	68	71	69	70	67	65	63	64	63
23	70	67	70	68	67	66	67	67	67	66	65	63	63	61
24	69	67			68	67	69	67	68	66	63	61	64	61
25	70	68			70	69	70	69	70	68	66	62	68	64
26	74	70			75	70	75	71	73	69	66	65	70	67
27	77	74			76	75	76	75	75	71	69	66	73	70
28	76	75			76	75	78	76	76	70	69	67	74	73
29	76	74			77	72	78	75	76	70	74	66	75	70
30	77	75			77	75	78	76	77	76	73	68	75	74
31	78	77			79	77	79	77	78	76	74	73	75	74
8/1	78	76			78	73	78	73	77	73	74	71	75	71
2	77	74			79	74	79	76	76	73	72	65	76	69
3	78	77			78	68	78	76	78	65	73	67	76	69
4	77	66			70	62	76	65	66	60	68	57	69	58
5	68	61			68	56	70	58	66	53	64	55	61	53
6	68	60			66	55	67	58	65	55	63	54	59	53
7	68	58			68	55	70	60	65	52	63	54	59	52
8	65	56	65	63	64	55	65	58	62	53	63	52	57	53
9	63	59	64	63	65	58	65	58	62	57	56	52	60	52

	Cook Plant										BH		SJ	
Offshore	300'				2,500'						3,375'		1,490'	
Depth	2'		4'		2'		12'		17'		40'		19'	
Date														
8/10/70	61°	55°	63°	61°	62°	54°	63°	58°	60°	52°	52°	51°	53°	50°
11	61	56	61	60	60	54	61	59	59	51	57	50	54	51
12	66	59	63	61	65	60	66	60	65	57	55	51	59	52
13	74	64	65	63	67	63	71	63	66	63	61	56	64	59
14	77	65	68	65	74	65	75	66	73	64	63	60	70	61
15	76	74	70	68	75	72	75	74	75	71	70	61	73	68
16	79	74	72	70	77	75	77	75	77	75	72	71	74	72
17	79	76	73	72	77	74	77	75	76	75	73	70	74	72
18	75	73	74	72	74	73	75	73	74	73	71	64	72	70
19	75	73	72	72	74	73	74	73	74	73	71	63	71	71
20											72	65	72	70
21											70	61	72	70
22											68	60	72	71
23											73	72	71	56
24											59	52	62	52
25											69	53	71	62
26											70	57	73	70
27											73	68	74	73
28	78	77	74	73	71	70	71	69	71	69	73	72	74	73
29	76	74	75	73	75	74	75	74	75	73	73	67	74	69
30	77	75	75	74	76	75	76	75	76	75	73	70	74	72
31	76	70	75	74	75	63	75	72	75	55	73	54	74	54
9/1	71	57	73	65	67	52	72	56	63	52				
2	67	53	66	61	68	52	69	55	66	50				
3			69	66	72	67	72	67	72	61				
4			71	70	72	71	72	71	72	71				
5			73	71	72	72	74	72	72	72				
6			73	72	72	72	72	72	72	72				
7			73	72	73	72	73	72	73	71				
8			74	73	73	73	73	73	73	73				
9			73	73	73	73	73	73	73	71				
10			73	72	73	72	73	72	73	71				
11			74	69	73	71	73	71	73	71				
12			72	69	72	70	72	70	71	70				
13			70	55	70	50	70	52	70	50				
14			57	49	54	49	54	48	50	47				
15			63	49	66	50	66	50	65	48				
16			63	48	63	47	64	48	59	47				
17			52	47	54	47	56	51	51	47				
18			56	51	55	50	57	54	54	50				
19			61	54	58	51	59	52	58	50				
20			66	59	64	58	64	59	63	57				
21			68	63	66	64	66	64	66	64				
22			68	66	67	66	67	66	67	65				
23			67	66	66	62	66	64	66	60				
24			65	63	64	61	65	63	65	55				
30	60	59	69	41	60	60	60	60	60	60	60	60	60	59

	Cook Plant										BH		SJ	
Offshore	300'				2,500'						3,375'		1,490'	
Depth	2'		4'		2'		12'		17'		40'		19'	
Date														
10/1/70	60°	58°	62°	36°	60°	59°	60°	59°	60°	59°	61°	60°	59°	58°
2	61	59	61	59	61	60	61	60	61	60	61	59	60	59
3	59	58			60	58	60	58	60	58	61	60	59	58
4	58	57			59	58	59	58	59	58	60	59	60	58
5	61	57	61	57	61	58	61	58	58	61	60	59	58	58
6	63	58	61	58	61	58	61	59	61	58	60	59	59	58
7	61	59	61	59	61	59	61	59	61	59	60	60	59	58
8	62	60	62	60	62	60	62	60	62	60	60	60	60	59
9	61	60	61	60	62	60	62	60	62	60	61	60	60	59
10	61	58	61	58	61	58	61	58	61	58	60	60	59	58
11	60	57	60	57	60	57	60	57	60	57	60	59	58	58
12	60	58	60	58	60	58	60	58	60	58	60	59	58	58
13	60	60	60	60	60	60	60	60	60	60	59	59	59	58
14	61	58	61	58	60	55	60	55	60	51	59	59	59	58
15	59	47	59	50	54	44	56	45	51	44	59	59	58	56
16	55	51	55	51	54	48	54	49	54	45	58	52	56	51
17	53	52	53	52	54	53	54	53	54	53	55	52	55	52
18	55	52	55	52	55	52	55	52	55	52	55	54	54	53
19	58	53	58	53	57	54	57	54	57	54	56	55	55	54
20	57	56	57	56	57	55	57	55	57	55	56	56	55	55
21	57	55	57	55	57	55	57	55	57	55	57	56	55	55
	56	55	56	55	55	55	55	55	55	55				
22	56	55	56	55	56	55	56	55	56	55	57	57	55	55
23	55	55	55	55	55	55	55	55	55	55	57	57	55	55
24	56	55	56	55	55	55	55	55	55	55	57	57	55	55
25	55	54	55	54	55	54	55	54	55	50	57	56	55	55
26	55	54	55	54	55	54	55	54	55	50	56	55	55	55
27	54	51	54	52	54	52	54	52	52	49	56	55	55	54
28	54	54	54	54	54	53	54	53	54	53	56	55	54	54
29	54	53	54	53	54	54	54	54	54	54	56	56	54	54
30	53	52	53	52	54	53	54	53	54	53	57	56	54	53
31	52	51	52	51	53	52	53	51	53	51	57	56	53	53
11/1	51	49	51	49	52	52	52	52	52	52	56	55	53	52
2	50	49	50	49	52	50	52	50	52	50	55	54	52	51
3	50	49	50	49	52	50	52	50	52	50	55	54	52	50
4	50	49	50	49	51	50	51	50	51	50	54	54	52	50
5	50	49	50	49	51	50	51	50	51	50	55	55	51	50
6	49	49	50	50	50	50	50	50	50	50	55	54	51	50
7	49	48	50	49	50	50	50	50	50	50	54	53	50	50
8	50	48	50	50	50	49	50	49	50	49	54	53	50	50
9	50	48	50	49	50	49	50	49	50	49	53	53	50	50
10	50	49	50	49	50	49	50	49	50	49	54	52	50	50
11	50	49	50	49	50	49	50	49	50	49	53	52	50	49
12	50	49	50	49	50	49	50	49	50	49	53	52	50	49
13	50	49	50	49	50	50	50	50	50	50	53	53	50	50
14	49	48	50	48	50	48	50	48	50	48	53	53	50	48
15	49	48	49	48	48	46	48	46	48	46	53	53	49	47
16	47	45	47	47	47	46	47	46	47	46	53	52	48	46

	Cook Plant										BH		SJ	
Offshore	300'				2,500'						3,375'		1,490'	
Depth	2'		4'		2'		12'		17'		40'		19'	
Date														
11/17/70	45°	45°	47°	46°	47°	46°	47°	46°	47°	46°	51°	51°	47°	46°
18	47	46	46	45	47	45	47	45	47	45	52	51	47	46
19	46	46	47	47	46	45	46	45	46	45	52	52	47	46
20	46	46	47	47	47	46	47	46	47	46	52	52	47	46
21	46	45	46	45	46	45	46	45	46	45	52	50	46	46
22	46	43	46	43	45	43	45	43	45	43	50	50	46	45
23	43	41	43	42	43	41	43	41	43	41	50	46	45	42
24	40	37			41	38	41	38	41	38	46	44	42	40
25	38	36			39	37	39	37	39	37	44	42	40	38
26											43	41	38	37
27											44	43	39	37
28											44	43	39	38
29											44	43	40	39
30											44	44	40	39
12/4	44	43			45	41	43	42	44	42	47	46	43	43
5	46	39			59	42	45	43	45	41	46	45	43	42
6	41	39			42	40	42	39	41	40	45	44	41	39
7	39	38			40	38	39	37	39	37	44	44	39	38
8	40	39			39	38	39	37	40	39	44	43	39	39
11	41	38			37	36	39	37	39	38	43	42	39	39
12	37	37			37	37	37	37	37	37	42	42	39	37
13	37	37			37	37	37	37	38	37	42	42	38	38
14	37	37			37	37	37	37	37	37	42	41	37	37
15	36	36			36	36	36	36	36	36	41	41	37	36
16	36	36			36	36	36	36	36	36	41	41	37	36
17	36	36			36	36	36	36	36	36	41	41	36	36
18	35	35			35	35	35	35	35	35	41	40	36	36
19	35	35			35	35	35	35	35	35	40	40	36	36
20	35	35			35	35	35	35	35	35	41	40	36	36
21	35	35			35	35	35	35	35	35	41	40	36	36
22	35	34			35	34	35	34	35	34	41	40	36	35
23	34	34			34	34	34	34	34	34	40	40	35	35
24	34	34			34	34	34	34	34	34	40	39	35	35
25	33	33			33	33	33	33	33	33	39	38	35	35
26	32	32			32	32	32	32	32	32	39	38	35	34
27	33	32			33	32	33	32	33	32	39	38	34	34
28	34	32			34	32	34	32	34	32	38	37	34	34
29	33	33			33	33	33	33	33	33	37	37	34	34
30	34	31			34	31	31	31	31	31	38	37	34	33
31	33	33			33	33	33	33	33	33	39	38	34	33
1/1/71	33	33			33	33	33	33	33	33	39	38	33	33
2	33	33			33	33	33	33	34	33	38	38	33	33
3	33	33			33	33	33	33	34	33	38	38	32	32
4	33	33			33	33	33	33	33	33	38	38	32	32
5	33	33			33	33	33	33	33	33	39	38	32	32
6	33	33			33	33	33	33	33	33	38	38	32	32

Offshore	Cook Plant									BH		SJ	
	300'			2,500'						3,375'		1,490'	
Depth	2'		4'	2'		12'		17'		40'		19'	
Date													
1/7/71	33°	33°		33°	33°	33°	33°	34°	33°	38°	38°	32°	32°
8	32	32		32	32	32	32	35	32	38	38	32	32
9	32	32		32	32	32	32	35	32	38	38	32	32
10	32	32		32	32	32	32	35	32	38	38	32	32
11	32	32		32	32	36	32	36	32	39	38	32	32
12	32	32		32	32	36	32	36	32	37	37	32	32
13	33	33		33	33	33	33	35	34	37	37	32	32
	36	35		31	30	33	30	36	34	37	37	32	32
14	36	35		30	29	30	29	36	35	37	37	32	32
15	35	34		30	29	31	30	36	35	37	37	32	32
16	35	34		30	29	30	29	35	34	37	36	32	32
17	35	34		32	32	31	30	35	34	36	34	32	32
18	35	34		32	32	31	31	34	34	35	34	32	32
19	34	34		32	32	32	32	34	34	34	33	32	32
20	34	34		32	32	32	32	34	34	33	33	32	32
21	34	34		32	32	32	32	34	34	34	33	32	32
22	34	34		32	32	32	32	34	34	34	32	32	32
23	34	34		32	32	32	32	34	34	34	32	32	32
24	34	34		32	32	32	32	34	34	33	32	32	32
25	34	34		32	32	32	32	34	34	33	32	32	32
26	35	34		33	32	32	32	34	34	32	32	32	32
27	35	34		33	32	34	34	34	34	32	32	32	32
28	34	34		33	33	32	32	34	34	34	32	32	32
29	34	34		33	33	32	32	34	34	35	34	32	32
30	34	34		33	33	32	32	34	34	34	34	32	32
31	34	34		33	33	32	32	34	34	34	34	32	32
2/1	34	34		33	33	32	32	34	34	34	34	32	32
2	34	34		33	33	32	32	34	34	34	33	32	32
3	34	34		33	33	32	32	34	34	34	34	32	32
4	35	34		34	33	30	29	31	30	35	34	32	32
5	35	34		33	33	30	29	30	30	35	35	32	32
6	34	34		33	33	30	29	31	31	36	35	32	32
7	34	34		33	33	31	31	31	31	36	35	32	32
8	34	34		33	33	30	30	31	31	36	36	32	32
9	34	34		33	33	30	30	31	31	37	36	32	32
10	34	34		33	33	30	30	32	32	37	36	32	32
11	34	34		33	33	31	31	32	31	37	36	32	32
12	36	34		33	33	31	31	32	31	37	37	32	32
13	35	34		33	33	31	31	32	31	37	37	32	32
14	34	34		33	33	31	31	32	32	37	36	32	32
15	34	34		33	33	31	31	32	32	37	36	32	32
16	34	34		33	33	31	31	32	32	37	36	32	32
17	36	34		33	33	31	31	32	32	39	33	32	32
18	36	34		33	33	31	31	32	32	37	35	32	32
19	35	34		33	33	31	31	32	32	38	35	32	32
20	34	34		33	33	31	31	32	32	37	35	32	32
21	34	34		33	33	31	31	32	32	37	35	32	32
22	34	34		33	33	31	31	32	32	35	35	32	32

	Cook Plant					BH	SJ
Offshore	300'		2,500'			3,375'	1,490'
Depth	2'	4'	2'	12'	17'	40'	19'
Date							
2/23/71	34° 34°		33° 33°	31° 31°	32° 32°	35° 35°	32° 32°
24	34 34		33 33	31 31	32 32	35 35	32 32
25	34 34		33 33	31 31	32 32	35 35	32 32
26	34 34		33 33	32 31	32 32	36 35	32 32
27	34 34		33 33	32 32	32 32	36 36	33 33
28	34 34		33 33	32 32	32 32	36 36	33 33

A.2 Study of Floating Algae and Bacteria

The record of water quality at the Cook Plant, particularly as it is expressed by the numbers and types of planktonic algae, is of prime importance to the ultimate assessment of whether the plant's waste heat has produced change in the local aquatic environment.

The planktonic algae live directly with and from the physical and chemical conditions of the aquatic environment. Being alive and irritable (sensing and responding to environmental change) they are apt to be that delicate and sensitive indicator of environmental change wherein the effects of the plant's waste heat should be watched for.

Unfortunately, the record contained in the planktonic algae is cumbersome to establish and difficult to work with. A customary and proper means of approach to whether changes in the aquatic environment have occurred is to establish, and watch for variations from, the annual cycles exhibited by these microscopic plants. Plankton algae parameters that are commonly watched are:

1. Variations in total numbers from year to year and from season to season within each year.
2. Variations in season to season dominant species, and comparisons of abundance of these dominants from year to year.

TABLE 2. Phytoplankton, Station PPP-10, Cook Plant, 25 April 1969.
Distance offshore -- 0.6 miles
Secchi disc -- n.d.
Water temperature -- n.d.
Water color -- n.d.

Organism	Number of Colonies	Cells/liter
Melosira spp.	2,766	18,532
Nitzschia sp.		277
Tabellaria fenestrata	12,447	71,639
Synedra ulna		11,894
Synedra acus		9,404
Fragilaria crotonensis	1,659	27,936
Cyclotella spp.		5,808
Asterionella formosa	277	1,106
Fragilaria intermedia	553	37,064
Diatoma tenue v. elongatum	553	1,936
Navicula sp.		277

3. Whether new species enter into the category of "dominant," and the algal type of the new dominants.

4. Whether statistical measures such as diversity indices, etc. in comparable seasons exhibit significant change over the longer period of record.

5. Unusual changes, whether interpretable or not, and whether there is a trend or trends in these changes.

To establish a record in which the data are adequate to carry on these surveillances requires as early a start as possible. To provide that start we have combined our phytoplankton data from stations in front of the Cook Plant (Tables 2 through 6) for the years 1969 and 1970. While the station positions are not geographically coincident, they are far enough offshore to provide some measure of the plankton algae that passed the site in the alongshore currents. The earliest of these stations (station PPP-10 of 25 April 1969) was taken by metered plankton net and is not quantitatively comparable to the others, though it is of value in indicating the dominant species.

TABLE 3. Phytoplankton, Station CP-2, Cook Plant, 11 August 1969.
Distance offshore -- 1.3 miles; sampled at 6 inches depth
Secchi disc -- n.d.
Water temperature -- n.d.
Water color -- n.d.

Organism	Number of Colonies	Cells/liter
Schroederia judayi		2,781
Peridinium sp.		66,744
Cryptomonas sp.		30,591
Chlamydomonas sp.		15,759
Oocystis sp.		26,883
Oocystis solitaria		8,343
Cyclotella sp.		305,910
Oscillatoria sp.		16,686
Mougeotia sp.		70,452
Anabaena sp.		7,416
Actinastrum hantzschii		65,817
Golenkinia radiata		1,854
Dinobryon divergens		9,270
Gloeocystis sp.		12,051
Cosmarium sp.		2,781
Closterium sp.		2,781
Ankistrodesmus falcatus		36,153
Ulothrix sp.		2,781
Pediastrum sp.		1,854
Treubaria setigerum		2,781
Quadrigula lacustris		927
Tetraedron minimum		927
Lagerheimia longiseta		2,781
Scenedesmus bijuga		1,854
Scenedesmus opoliensis		11,124
Scenedesmus quadricauda		2,781
Scenedesmus incrassatulus		7,416
Kirchneriella obesa		1,854
Nephrocytium		927
Synedra ulna		9,270
Synedra sp.		1,854
Synedra delicatissima		5,562
Crucigenia apiculata	927	3,708
Melosira granulata	12,051	61,182
Tabellaria fenestrata	5,562	18,540
Melosira granulata v. angustissima	15,579	53,766
Dictyosphaerium pulchellum		2,781
Melosira binderana	927	6,489
Melosira sp. 1	927	7,416
Synedra acus		927
Tetraedron lunula		927
Aphanizomenon flos-aquae		927
Tetrastrum sp.		1,854
Fragilaria crotonensis	1,854	12,051

TABLE 4. Phytoplankton, Cook Station, Lake Michigan Environmental Survey, 4 October 1969.

Distance offshore -- 1 mile; sampled at 15 m depth
Secchi disc -- 3.0 m
Water temperature -- 18.0°C
Water color -- slightly milky brownish-green

Organism	Number of Colonies	Cells/liter
Chroococcus colonies	3,708	
Anabaena sp.		1,854
Chlamydomonas spp.		92,700
Flagellates		128,853
Cyclotella spp.		893,628
Dinobryon sp.		13,905
Asterionella formosa	3,708	36,153
Oocystis sp.		36,153
Scenedesmus sp.		32,445
Tabellaria fenestrata	8,343	36,153
Dictyosphaerium pulchellum		9,270
Tetraedron sp.		2,781
Melosira binderana	1,854	10,197
Melosira granulata	135,342	704,520
Gomphosphaeria sp.		7,416
Coelastrum sp.		12,978
Cosmarium sp.		4,635
Closterium sp.		927
Aphanocapsa sp.		15,759
Lagerheimia sp.		5,562
Ankistrodesmus falcatus		19,467
Stephanodiscus niagarae		927
Navicula sp.		927
Crucigenia sp.		927
Nitzschia sp.		3,708
Synedra sp.		4,635
Pediastrum sp.		927
Fragilaria crotonensis	2,781	20,394

TABLE 5. Phytoplankton, Cook Station, Lake Michigan Environmental Survey, 26 April 1970.

Distance offshore -- 1 mile; sampled at 15 m depth

Secchi disc -- 1.75 m

Water temperature -- 8.3°C

Water color -- greenish

Organism	Cells/liter
Cyclotella sp.	241,150
Chlamydomonas spp.	252,280
Tabellaria fenestrata	131,705
Fragilaria crotonensis	14,840
Ankistrodesmus falcatus	63,070
Mallomonas spp.	38,955
Peridinium	22,260
Dinobryon divergens	31,535
Synedra filiformis	1,855
Quadrigula chodatii	1,855
Synedra ulna	12,985
Phormidium sp.	9,275
Melosira granulata	25,970
Cryptomonas spp.	18,550
Fragilaria intermedia	27,825
Nitzschia sp.	7,420
Melosira binderana	152,110
Melosira islandica	371,000

TABLE 6. Phytoplankton, Cook Station, Lake Michigan Environmental Survey, 6 June 1970.

Distance offshore -- 1 mile; sampled at 15 m depth
Secchi disc -- 3.2 m
Water temperature -- 12.3°C
Water color -- milky light green

Organism	Number of Colonies	Cells/liter
Closterium sp.		3,708
Ankistrodesmus falcatus		16,686
Fragilaria crotonensis		62,109
Achnanthes sp.		2,781
Dinobryon divergens		9,270
Synedra ulna		4,635
Synedra ulna v. danica		21,321
Cymatopleura solea		927
Synedra ostenfeldii		7,416
Phormidium sp.		5,562
Fragilaria intermedia		18,540
Melosira islandica	3,708	34,299
Melosira granulata		18,540
Synedra filiformis		8,343
Peridinium sp.		1,854
Nitzschia spp.		62,109
Oscillatoria sp.		8,343
Tabellaria flocculosa		3,708
Dinoflagellates		1,854
Cyclotella spp.		247,509
Tabellaria fenestrata		242,874
Chlamydomonas spp.		94,554
Cryptomonas spp.		27,810
Amphora ovalis		927
Gomphonema sp.		927
Synedra v. chaseana		1,854
Fragilaria capucina		18,540

The rest of the data were collected by quantitative settling-out of phytoplankters from a liter of water after preservation with Utermohl's iodine fixative. Depths of sampling in the latter stations range from just under the surface to 15 meters.

The following rough beginning of the Cook site annual cycle of planktonic algal water quality is presented as that cycle which will be supplemented and developed as additional data become available.

In the summary of the planktonic algae in Table 7 we define: Winter as being December, January, and February; Spring as being March, April, and May; Summer as being June, July, and August; and Fall as consisting of September, October, and November. Samples during winter are at present impossible for us.

We can make the following comments about these data: 1) evidence from the Chicago Water Department indicates in their nearshore water a heavy dominance of diatoms during winter, consequently we do not consider that the May 1970 diatom abundance is a yearly maximum; 2) there appears to be an increase (in numbers of species, at least) of blue-green algae from spring into fall; 3) green algae appear to have a peak in late summer that may or may not be supported by subsequent data; and 4) the persistence of flagellates is unexpected and may or may not be supported by subsequent data.

<u>Statistical Treatment of Phytoplankton Records</u>. The phytoplankton records of the Cook Plant surveys are by far the most difficult to interpret of all the data being obtained, yet they are probably the most sensitive indicators of water quality. Statistical aids to their interpretation are considered necessary.

We propose to try the computation and interpretation of the diversity index, or such other parameters as informed statisticians may devise, to see

TABLE 7. Summary of Cook Plant planktonic algae to date.

Month & year	Organisms	No. of species	Cells per liter
		SPRING	
April 1970	Diatoms	10	987,000
	Green algae	2	65,000
	Flagellates	5	364,000
	Blue-greens	1	9,000
May 1970	Diatoms	21	3,120,000
	Green algae	9	250,000
	Flagellates	5	544,000
	Blue-greens	2	30,000
		SUMMER	
June 1970	Diatoms	18	757,000
	Green algae	2	20,000
	Flagellates	5	135,000
	Blue-greens	2	14,000
August 1969	Diatoms	11	483,000
	Green algae	26	274,000
	Flagellates	4	122,000
	Blue-greens	3	25,000
		FALL	
October 1969	Diatoms	10	1,711,000
	Green algae	11	126,000
	Flagellates	3	235,000
	Blue-greens	4	29,000

whether (over time) interpretable statistical parameters change, and hence indicate change in water quality.

The Cook Plant preoperational surveys produce 52 phytoplankton analyses three times a year. Each set is distributed over the logarithmically-arranged sampling station grid described and illustrated in pages 66-69 of Part IV of our report series. These sets of samples are the largest that can be worked up; it is believed that they represent sufficiently large samplings to justify statistical treatment.

This portion of the program is admittedly experimental. We do not yet know whether it will produce the desired results.

An Undesirable New Alga in the Cook Plant Phytoplankton. On 10 July 1970 the first full-scale biological survey of the Cook Plant area was carried out. Included in this survey were 52 phytoplankton samples, the analyses of which are only now being completed.

At Station SDC-1-2 of this survey the phytoplankton sample obtained at 1-meter depth in milky brownish-green water (that we believe is St. Joseph River water) contained abundant numbers of what appear to be a strange dinoflagellate alga hitherto not reported from Lake Michigan, and only twice previously reported from the United States. In its full blooms this alga produces milky water color, disagreeable odor, and thick white surface "flocs" that interfere with recreational activities.

Ahearn, Hall, and Reinhardt (1971) report blooms of this *Hypnodinium*-like alga in lakes in Georgia river systems in 1968, 1969, and 1970. In the Georgia lakes the blooms appear to be related to both the beginning of summer thermal stratification and to inputs of sewage, both of which conditions can be met in St. Joseph River water discharged into Lake Michigan. Their complete paper is included as page 18.

Occurrences of milky water have been widespread in Lake Michigan since 1966. The milky water of Lake Michigan has not involved a white surface scum nor has it been relatable to influents of sewage. There is no evidence at this time that the milky water color of Lake Michigan is related to the presence of this organism. This organism, however, with its undesirable bloom characteristics, is one for which careful watch will be kept in subsequent phytoplankton analyses.

Research Reports

Hypnodinium-like Algal Blooms in Georgia Lakes

Since 1968, we have observed each June an algal bloom of varying intensity lasting 7-10 days in Lake Sidney Lanier. The lake, the largest in Georgia, is a young, man-made reservoir 72.4 km north of Atlanta, measuring about 150.2 km^2 with a maximum depth of 54.9 m. In 1969, the surface of the lake turned milky white (Fig. 1A). In 1970, the white bloom was of a low intensity in Lake Lanier, but of heavy density in lakes Jackson (5 June), Cardinal (22 June), and Buckhorn (25 June). These lakes are situated on different river systems in northwest Georgia.

The alga was seen in 1970 in Lake Lanier on 19 June, reached maximum concentrations around 23 June, and almost had disappeared by 28 June. Dense surface flocs (10^5-10^9 protoplasts/ml) covering 3 to 20 m^2 patches were found only in the embayment area of Flat Creek. This region of Lake Lanier receives sewage effluents, a phenomenon common to all the 1970 bloom sites. Prior to, during, and after the bloom, hydrographic conditions in the Flat Creek area were monitored. The bloom occurred shortly after the water stratified with a thermocline near 9 m. The surface water temperature was 28 C, the pH 9.1, and the dissolved oxygen 8.2 mg/liter. At the thermocline the water temperature was about 17 C, the *p*H 8.3, and the dissolved oxygen 3.4 mg/liter. Four days prior to the recording of the bloom the fecal coliform density increased from <4/100 ml to >240/100 ml. By 30 June, the coliform density was <3/100 ml. An increased amount of untreated sewage appeared to precede the bloom.

The milky white surface scum from all four lakes was composed primarily of tan to orange-brown, oval to spheroidal bodies ranging on the longest axis from 32 to approximately 75 μ (Fig. 1B). The bodies were surrounded with a clear envelope which stained light blue to purple with chloriodide of zinc, which suggested the presence of cellulose. The envelope contained one or a few distinct, large protoplasmic bodies of varying size. A single dark protoplasmic body was present within most envelopes. Occasionally, one or two light, thick-walled macrospores were also found within the envelope. The dark protoplast matured into a dark macrospore with a definite cell wall which also stained blue with chloriodide of zinc. This macrospore subdivided and produced from 2 to 15 or more bi-pored microspores (Fig. 1C). The wall of the mature dark macrospore ruptured, with the subsequent release of mature microspores. The microspores were spheroidal, ranging in diameter from 9.1 to 15.6 μ, averaging 11.7 μ. Each microspore possessed two circular pores directly opposite each other (Fig. 1D). Each

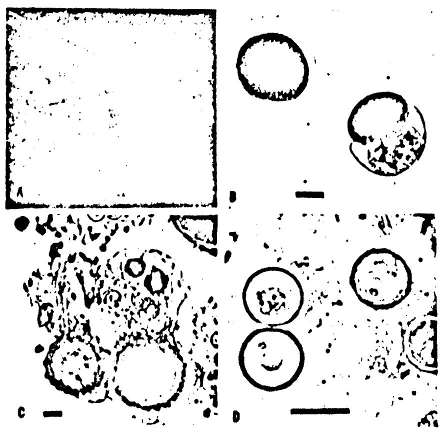

Fig. 1. Aerial view of surface bloom of brown alga on Lake Sidney Lanier, Georgia, in June 1969. The trail in the water is the displacment of the bloom by the boat's wake. (A) Protoplasts enclosed in envelopes. (B) Immature and matured dark macrospores. (C) Mature bi-pored microspores. (D) B, C, and D are unstained live material; scale bars, 10 μ.

spore contained a single protoplasmic body (about 5.8 μ in diameter) located next to one of the pores. In older preparations the microspores appeared to be empty. Although movement within microspores occurred, no exit of the protoplasmic body through the pores has been observed. Bi-flagellated zoospores resembling the protoplasmic bodies of the microspores occurred in large numbers in the microscope preparations. In several instances, zoospores swam within the apparently intact envelope. The zoospores swam with a spiraling motion and appeared to have a short anterior tinsel flagellum and a trailing posterior whiplash flagellum. We are attempting to determine the complete life cycle and to grow the organism in axenic culture.

This alga grossly resembles *Hypnodinium sphaericum* Klebs, 1912, an ill-defined species only once previously reported from the United States (Thompson, 1949). However, the bi-pored cells of this alga make it distinct from *H. sphaericum*. A taxonomic description will appear elsewhere. The alga has not been directly associated with any fish kills. A disagreeable odor accompanies the bloom and the thick surface flocs interfere with recreational activities. The significance and long-term effects of this alga on the lakes are unknown. Considering the capacity of the alga to produce rapid and massive blooms, we recommend intensive monitoring of lake ecology following detection of this *Hypnodinium*-like species.

Acknowledgments

Supported in part by a contract from the U.S. Army Corps of Engineers, Mobile District, and by the State Water Quality Control Board of Georgia. We thank Mr. G. N. Smith for technical assistance.

References

Thompson, R. H. 1949. Immobile Dinophyceae. 1. New records and a new species. *Amer. J. Bot.*, 36: 301-308.

DONALD G. AHEARN
Department of Biology
Georgia State University
Atlanta, Georgia

EDWARD T. HALL, JR.
Georgia Water Quality Control Board
47 Trinity Avenue, S.W.
Atlanta, Georgia

DONALD J. REINHARDT
Department of Biology
Georgia State University
Atlanta, Georgia

(Accepted for publication 11/19/70)

Previous phytoplankton samples collected from water of brownish-green color indicate (at least to the extent that the same analyst had not previously noticed this dinoflagellate) that the organism has not before been present in our samples.

From this we do not conclude that noxious blooms of this algal form are an immediate threat. We do, however, conclude that the presence of one more algal form capable of producing nuisance blooms cannot be indicative of improving water quality in the lake.

A.3 Development of a Monitor for Phytoplankton

In response to a very pressing need for a more rapid way in which to assess the numbers of living phytoplankters in the water of Lake Michigan, we attempted a direct attack upon what amounts to two problems simultaneously.

We continually need to know, rapidly, the numbers of phytoplankton in any given area of lake water. Particle counters can count the numbers of particles passing in a stream of pumped water; they cannot, however, differentiate between live phytoplankton, long-dead phytoplankton, or simple particulate detritus. Live phytoplankton, or phytoplankton so recently dead that they still retain their chlorophyll, will fluoresce under ultraviolet light.

We thought, and still think, that a workable means of counting passing fluorescing particles in a stream of pumped water will provide some relief from laborious microscopic counting of phytoplankters (with no way of telling which are dead).

A counter of passing fluorescing particles was conceived of as being a small chamber on the stage of a microscope provided with substage illumination with ultraviolet light while the top of the microscope's optical tube was equipped with a photomultiplier and an amplifier to provide needed signal strength.

We have succeeded in developing what appears to be an adequate chamber for the microscope stage. It withstands city-supply water pressure without leakage, it apparently does not develop flow separation, and it has desirable qualities of not clogging in turbid-water conditions.

We have, however, found that the common commercially available sources of ultraviolet light are deficient in intensity, and that they contain substantial amounts of non-ultraviolet light which must be filtered out. The photomultipliers so far tried are unacceptably noisy under the direct ultraviolet lighting conditions which have been tried.

We continue to investigate sources of more intense and better spectrally-controlled ultraviolet-light sources. It is planned to reconfigure the instrument to avoid having the photomultiplier look directly at the light source.

We are also planning to combine a Turner fluorometer with a Hiac particle counter as an interim measure.

A.4 Study of Attached Algae

Initial Periphyton Samples. Two periphyton samples were obtained on 21 October from plastic subsurface floats attached to periphyton collectors that had not been successful. The collectors had been set on 23 September. The plastic subsurface floats were at depths of about six feet; their function was to aid our divers in finding the collectors. The floats had a smooth surface finish from which the periphyton were scraped.

The samples are qualitative only, but are adjudged adequate to indicate the dominant periphyton types native to the Cook Plant area in fall.

The periphyton was very sparse, and was heavily dominated by diatoms of the genera *Gomphonema*, *Nitzschia*, *Synedra*, *Achnanthes*, and *Cymbella*. The dominant diatom was *Gomphonema sp.*, though *Melosira varians* (a supposed pollution indicator) was also quite abundant.

One green alga of the genus *Stigeoclonium* was present in some numbers but was not a dominant. There was no *Cladophora* present.

The Periphyton-Collector Problem. Two different designs of bottom-mounted periphyton collectors have failed to survive the inshore environment at the Cook Plant.

The brute-strength approach having been unsuccessful, we are going to use collectors of a design recommended by James Truchan of the Michigan Water Resources Commission's Water Quality Appraisal Section. These collectors will be screw-anchored to the bottom, will present collecting surfaces near the water surface, and will yield to wave action. We anticipate that these collectors can be set in April.

A.5 Study of Zooplankton

The results of zooplankton studies to date are sparse, but to get them into the record as data antecedent to the detailed biological surveys they have been assembled and are reported here.

Minor computational errors in the data of 25 April 1969 have been corrected in Table 8. Table 9 presents the zooplankton collected in our three occupations of the station 1 mile off the Cook site during the Lake Michigan Environmental Surveys.

Through 1970 our zooplankton collections have been made with metered #5 plankton nets. Because this net has a mesh sufficiently large to allow the escape of the smaller zooplankters, the smaller-mesh #10 net will be used routinely in the future.

A.6 Study of Aquatic Macrophytes

On 13 October 1970 the bottom off the Cook Plant site was surveyed for

TABLE 8. Power plant surveys - primary zooplankton counts, Cook Plant, Lake Michigan, 25 April 1969. Number of organisms per liter.

	PPP-1 35 ft	PPP-3 15 ft	PPP-10 35 ft	PPP-12 15 ft	PPP-19 35 ft	PPP-21 15 ft
CALANOID COPEPODS						
Diaptomus sp.	0.18	0.37	0.36	2.64	0.23	0.43
Epischura lacustris	0.01			0.30		
CYCLOPOID COPEPODS	0.01	0.09	0.04	0.05	0.05	0.08
CLADOCERA						
Bosmina sp.						0.02

TABLE 9. Primary zooplankton, Cook station, Lake Michigan Environmental Surveys. Number of organisms per liter.

	4 Oct. 1969	26 Apr. 1970	6 June 1970
COPEPODS			
Calanoids			
Diaptomus spp.	0.40	3.06	4.01
Senecella spp.	-	-	-
Epischura spp.	-	-	-
Eurytemora spp.	-	-	-
Limnocalanus spp.	-	0.17	0.01
Cyclopoids	0.04	2.99	8.25
Harpactacoids	-	-	-
CLADOCERANS			
Bosmina spp.	0.83	0.01	0.57
Daphnia spp.	0.14	0.01	0.02
Polyphemus spp.	0.01	-	0.01
Alona spp.	-	-	-
Leptodera spp.	0.04	-	-
Holopedium spp.	0.01	-	-
Ceriodaphnia spp.	-	-	-
Diaphanosoma spp.	-	-	-
ROTIFERS			
Asplanchna spp.	0.16	-	0.29

macrophyton (rooted aquatic plants). The R/V MYSIS was used as the support vessel from which this work was conducted. The MYSIS anchored at the offshore end of transect 1, directly off the South Range Pole at a depth of 17 meters, and remained there acting as a fixed reference point for the small boat during the runs of both transects 1 and 2. After completion of transects 1 and 2 the MYSIS moved to the offshore end of transect 3, directly off the North Range Pole, and anchored in 16.5 meters of water remaining there during the running of transects 3 and 4.

A 16 foot Zodiac inflatable boat powered by a 9 1/2 horsepower outboard engine towed the divers along the four transects (Fig. 1) at approximately 2 knots. The towing apparatus consisted of approximately 175 feet of 1/2 inch line tied at one end to a V-shaped harness on the stern of the Zodiac, and tied at the other end to another V-shaped harness which had two underwater planing boards attached to it. With the planing boards the divers were able to skim the lake bottom and collect any macrophyte samples available.

The divers used conventional open circuit scuba equipment.

Date 13 October 1970 Dive No. 1

Location Transect No. 1 - directly off South Range Pole

Depth 17 to 6 meters

Team Bob Anderson, Tom Bottrell Dive time 33 minutes

Work Brief/Notes. The divers descended the anchor chain of the MYSIS, anchored in 17 m, to the bottom and then proceeded towards shore on transect number one. Along the anchor chain the surface water temperature was 16°C, the thermocline was located at a depth of 9 m, and the water temperature on the bottom was 12°C. Visibility near bottom varied from zero to 2 m.

In the depth range from 17 to 12 m the bottom type consisted of a sandy silt. Small bifurcating ripple marks were present in this area indicating

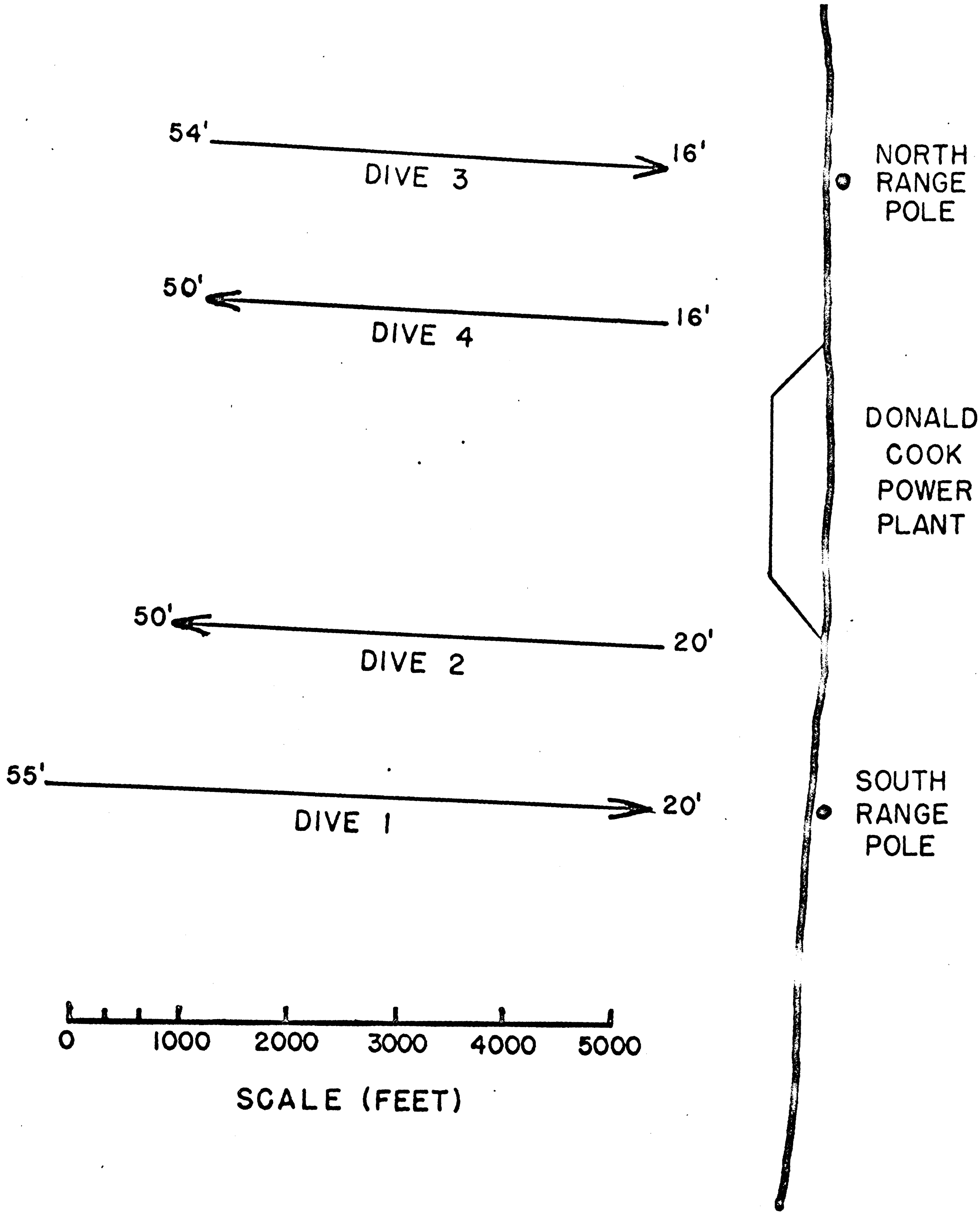

FIG. 1. Macrophyte survey, 13 October 1970.

some turbulence on the bottom. Small patches of black organic material were found on top of the silt in this area.

Several pockets of silt were found in the 17 to 10 m depth zone along this transect. Although these pockets of silt varied somewhat in size, they all averaged about 25 to 30 cm in depth. Silt depth was estimated by pulling a vertically held forearm through the pockets while the extended fingers remained in contact with firm bottom.

At a depth of 12 m the bottom type became a silty sand exhibiting large bifurcating ripple marks. The wave length of the ripple marks was about 30 cm and their heights varied from 10 to 16 cm.

During the last 91 m of this transect visibility was reduced to near zero because of dredging operations at the plant site. The dive was terminated at a depth of 6 m.

No macrophytes were observed on transect number one. The bottom topography indicated a degree of turbulence which would not offer a stable environment for macrophytes.

Date 13 October 1970 Dive No. 2

Location Transect No. 2 - one-quarter mile north of Transect No. 1

Depth 6 to 15 meters

Team Bob Anderson, Tom Bottrell Dive time 23 minutes

Work Brief/Notes. Boarded the Zodiac at the completion of transect number one and moved approximately one-quarter of a mile north of transect one. Started transect number two at a depth of 6 m and proceeded offshore.

The observations made during this dive were almost identical to those made on dive number one. The bottom type out to a depth of 12 m consisted of a silty sand. Large bifurcating ripple marks were again found in the area of silty sand. The bottom type in the area between 12 and 15 meters

consisted of a sandy silt with small black patches of organic material present on top of the sediment. Several pockets of silt were found. Dive number two was terminated at a depth of 15 m. No macrophytes were observed on transect number two.

Date 13 October 1970 Dive No. 3

Location Transect No. 3 - directly off North Range Pole

Depth 16.5 to 5 meters

Team Bob Anderson, Tom Bottrell Dive time 31 minutes

Work Brief/Notes. The MYSIS proceeded north of the Cook Plant and anchored directly off the North Range Pole at a depth of 16.5 m. The divers descended the anchor chain of the MYSIS to the bottom and proceeded under tow of the Zodiac towards shore on transect number three. The bottom type at 16.5 m was a sandy silt. Several pockets of silt 10 to 15 cm in depth were observed between the depths of 16.5 and 12 m. Small black areas of organic material 5 to 8 cm in diameter were abundant in these areas of silt. The bottom type at a depth of 12 m or less consisted of a silty sand exhibiting bifurcating ripple marks with wave lengths of 30 to 45 cm and heights of 10 to 15 cm. The trend of the ripple marks was in a north-south direction. Large amounts of detritus had collected in the troughs of the ripple marks. The detrital material was composed of dead *Cladophora* with stems, roots, and leaves of terrestrial plants mixed in. The *Cladophora* had been washed into the area, as none was observed in the vicinity of the Cook Plant. A clump of sedges was also found on the bottom. Sedges being native to swamps, it had definitely been washed into the area. Several tree branches were found on the bottom. Chunks of a woody material that were easily broken and resembled peat were also found scattered along transect number three.

During the end of this dive we passed over two sandbars. Large amounts of detritus, composed mainly of *Cladophora* had collected in the area of these sandbars. Dive number three was terminated at a depth of 5 m. No macrophytes were observed on transect number three.

Date 13 October 1970 Dive No. 4

Location Transect No. 4 - one-quarter mile south of Transect No. 3

Depth 5 to 15 meters

Team Bob Anderson, Tom Bottrell Dive time 25 minutes

Work Brief/Notes. Boarded the Zodiac and moved approximately one-quarter mile south of transect number three. The depth at the starting point of transect number four was 5 m. The bottom topography observed throughout this dive was quite similar to that of transect number three. We passed over the two sandbars but no detritus had accumulated in this area. The bottom type out to a depth of 12 m was a silty sand exhibiting bifurcating ripple marks. No detritus was found in the troughs of the ripple marks.

The bottom type in the 12 to 15 m depth zone consisted of a sandy silt. Several pockets of silt were again located in this area and the black organic spots described previously were also present. Several chunks of a woody material resembling peat were found at depths of 9 to 15 m. This material was found on top of the sediment and had evidently recently been washed into the area. Dive number four was terminated at a depth of 15 m. No macrophytes were observed along transect number four.

We intend to repeat the macrophyton survey during the summer and fall of 1971, and to accompany these surveys with bottom-condition photographs to show the nature of the ripple-marks, the silt pockets, the accumulations of detritus, and the absence of macrophyton.

A.7 Study of Benthic Organisms

In order that the benthos record relative to the Cook Plant may be as complete as possible, the benthos results from our surveys prior to the beginning of the present detailed biological surveys have been assembled and are here reported.

The surveys were taken for different purposes and over different grids of sampling stations and there is only limited comparability among them. The survey of 13 July 1966 was part of a general orientation survey which was reported in pages 12-16 of Part I of our report series. The survey of 25 April 1969 was made to determine the sampling depths that define the waveswept "sterile zone" close to the beach; this survey was reported in pages 52-66 of Part IV of our report series. These surveys have comparability only insofar as the "sterile zone" is concerned.

The COOK station data of 4 October 1969, 26 April 1970, and 6 June 1970 involved the same sampling location as station PPP-14 of the July 1966 survey. This location is also station DC-3 of our present detailed surveys (for which no results are yet available). No station of the 25 April 1969 survey (Table 10) is comparable to this location.

We start the accumulation of the Cook annual cycle of benthos abundance by the following compiled from Tables 11 and 12, which were all collected by the Ponar grab sampler and washed through 0.5 mm screen.

Station and date	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
26 IV 70 COOK	286/m^2	1,165/m^2	399/m^2	304/m^2	26/m^2 Leeches
6 VI 70 COOK	1,504	243	43	52	0
13 VII 66 PPP-14	316	101	21	208	0
4 X 69 COOK	1,965	939	521	313	0

TABLE 10. Benthos, numbers per meter^2, Donald C. Cook plant site, 25 April 1969.

Station	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
PPP-1	0	260	26	408	0
PPP-2	34	834	52	226	0
PPP-3	0	8	8	0	0
PPP-4	8	130	78	199	0
PPP-5	0	652	8	165	0
PPP-6	0	0	0	8	0
PPP-7	8	139	269	130	0
PPP-8	0	513	34	130	0
PPP-9	0	0	0	17	0
PPP-10	17	556	130	226	0
PPP-11	0	130	8	86	0
PPP-12	0	0	0	8	0
PPP-13	17	566	86	434	0
PPP-14	0	8	8	34	0
PPP-15	0	0	0	0	0
PPP-16	26	147	17	139	0
PPP-17	0	8	8	8	0
PPP-18	0	0	0	0	0
PPP-19	104	391	43	113	0
PPP-20	0	43	0	52	0
PPP-21	0	0	0	0	0

This is only a beginning, and cannot yet be interpreted. It suggests that substantial seasonal variations may be present, and indicates that the four major groups of benthos are probably present throughout the year.

A.8 Study of the Local Fishes

Through the kindness of Mr. Mercer H. Patriarche of the Michigan Department of Natural Resources Institute for Fisheries Research, we have

TABLE 11. Cook Plant benthos survey, 13 July 1966. Samples at 15 feet of depth, at 1 mile, at 2 miles, and at 3 miles offshore. Sampling lines perpendicular to shore. Organisms in numbers per square meter.

Sample	Location	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
PPP-5	1/2 mile south of Livingston Rd., 15 feet	0	1,877	0	279	6
PPP-6	1 mile offshore	144	501	6	552	6
PPP-7	2 miles offshore	6,379	10,993	974	129	79
PPP-8	3 miles offshore	14,992	4,042	1,318	129	58
PPP-9	Off Livingston Rd., 15 feet	0	14,506	6	165	0
PPP-10	1 mile offshore	230	14,400	394	616	0
PPP-11	2 miles offshore	10,040	866	466	114	36
PPP-12	3 miles offshore	6,923	11,567	1,404	221	64
PPP-13	Off center of plant site, 15 feet	28	1,984	6	135	0
PPP-14	1 mile offshore	316	101	21	208	0
PPP-15	2 miles offshore	4,171	12,728	2,199	178	107
PPP-16	3 miles offshore	14,835	5,446	1,240	86	0
PPP-17	Off north edge of plant site, 15 feet	21	150	15	193	0
PPP-18	1 mile offshore	565	3,726	129	780	6
PPP-19	2 miles offshore	5,138	759	221	114	15
PPP-20	3 miles offshore	12,261	6,321	1,133	107	129

TABLE 12. Benthos, numbers per meter^2, Cook Station, Lake Michigan Environmental Survey. Distance offshore: nominal 1 mile. Depth of water: 48-50 feet.

Date	Amphipods	Oligochaetes	Sphaeriidae	Tendipedidae	Others
4 Oct. 1969	1,965	939	521	313	0
26 Apr. 1970	286	1,165	399	304	26 - leeches
6 June 1970	1,504	243	43	52	0

received a list of 28 fish species taken during the past three years around Consumers Power Company's Palisades Nuclear Plant near South Haven, Michigan.

The fish were obtained by gill-netting four times a year in depths of 20 and 40 feet, by several beach-seine hauls, and by trawling twice one summer in depths of 18, 42, and 72 feet.

Below is the list of 28 fish species taken. Those marked with an asterisk were captured in shallow water (3 feet or less) by seine but some were taken in greater depths as well. Those with a double asterisk were captured only by seine:

Spottail shiner *	Sculpin (*C. bairdii*) **	Quillback **
Longnose dace **	Yellow perch *	Smallmouth bass **
Lake trout *	White sucker *	Black bullhead **
Chinook salmon *	Coho salmon,	Common shiner **
Alewife *	Smelt	Golden redhorse
Johnny darter **	Trout-perch	Lake herring
Lake emerald shiner **	Longnose sucker	Mud pickerel **
Bloater (*L. hoyi*) *	Channel catfish	Northern pike
Bluegill **	Carp **	Burbot **
Round whitefish		

In personal communication to J. C. Ayers, Mr. Patriarche has pointed out that the inclusion of the round whitefish in the list is based upon only 3 specimens caught in the first year of the Palisades surveys.

Mr. Patriarche suggests, and we agree, that the 30 miles between the Palisades and Cook plants along the open Michigan shore should make little difference between the two plant sites.

There being no other fish data yet obtained, we accept the list of fishes captured at Palisades as being the best probable indication of the local fishes at the Cook Plant.

At present we are uncertain when active collection of fishes at the Cook Plant can be begun.

A.9 Support of Aerial Scanning

On 7 May 1970 we carried out a program of lake-truth stations requested by the Willow Run Remote Sensing Laboratories for their flyover of the Cook Plant lake environs. Per their request we attempted to provide stations at measured distances off the beach, and to take at each of these stations water transparency, surface water temperature, water color, and phytoplankton samples.

Willow Run's request was for stations at each 200 feet of distance from the beach out to 4000 feet. Our line was laid outward from the north range markers of the Cook Plant property. With Indiana and Michigan's small aluminum boat at the water's edge, two turns of stout butcher's twine were passed around the sheave of a GM foot-wheel and the line end attached to the outer of the north range poles on the north edge of the Cook site property, and the wheel was zeroed at that position with the twine taut. After pushing and poling the boat away from shore, a course offshore along the north range line was steered at slow speed. At each 200 feet of measured distance from shore a small styrafoam buoy on a premeasured length of anchor line was dropped. This system worked well out to 3000 feet, after which the premeasured anchor lines were too short and the buoys were taken under. The 4000 feet proposed by Willow Run was thus shortened to 3000 feet.

After setting the buoys, a depth sounding run was started along the line of buoys, but at 2200 feet from shore the outboard motor quit and the whole operation was rowed ashore for motor repairs that were at best only partially successful.

With the repaired motor we went out to the 3000 foot end of the line of measured distances from shore and began the physical and biological sampling required by the Willow Run laboratories. The results are presented in Figure 2 and in Tables 13 through 17.

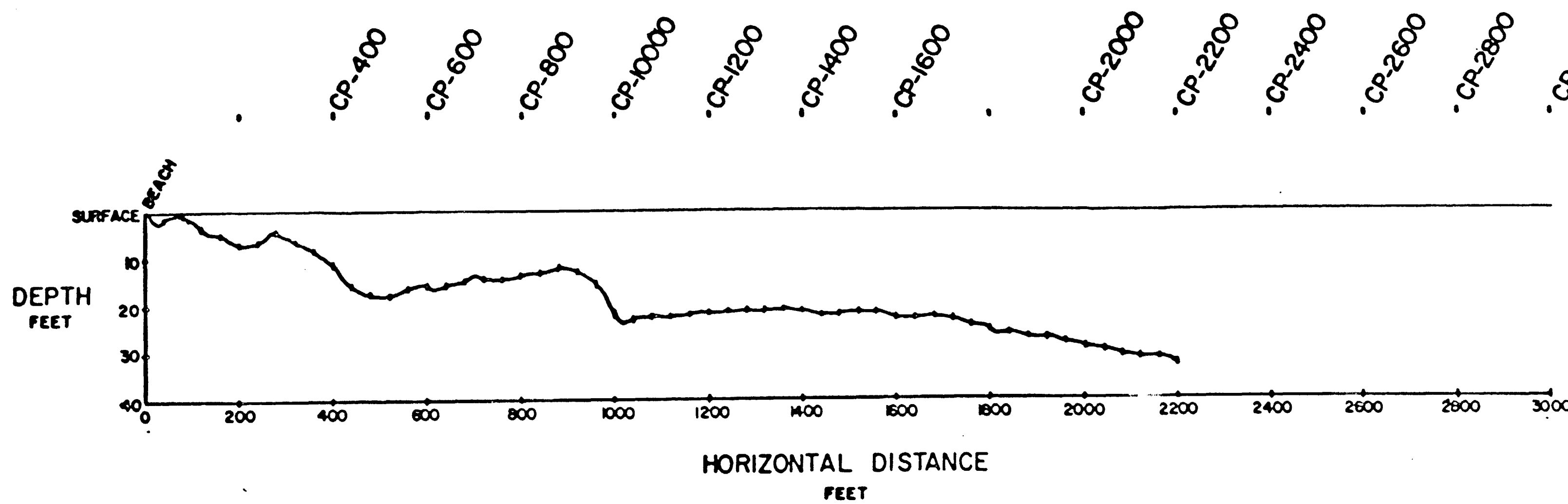

FIG. 2. Donald Cook Nuclear Power Plant flyover, 7 May 1970.

TABLE 13. Cook Plant flyover, 7 May 1970. Wind SW force 4 (20 mph).

Measured feet from shore	Secchi	Surface temp. °C	Phytoplankton sample (4" under surface)	Water color
200	buoy lost			
400	1.0 m	9.9° 9.9°	CP-400	greenish brown
600	1.3 m	9.2° 9.2°	CP-600	brownish green
800	1.6 m	9.1° 9.1°	CP-800	brownish green
1,000	1.5 m	9.0° 9.0°	CP-1000	brownish green
1,200	1.6 m	8.8° 8.8°	CP-1200	slightly brownish green
1,400	1.8 m	8.8° 8.8°	CP-1400	very slightly brownish green
1,600	1.8 m	8.5° 8.5°	CP-1600	very slightly brownish green
1,800	missed			
2,000	2.0 m	8.1° 8.1°	CP-2000	very slightly brownish green
2,200	2.2 m	8.0° 8.0°	CP-2200	very slightly brownish green
2,400	2.2 m	8.1° 8.1°	CP-2400	very slightly brownish green
2,600	2.0 m	8.4° 8.4° 8.3°	CP-2600	very slightly brownish green
2,800	2.0 m	8.8° 8.8°	CP-2800	slightly brownish green
3,000	2.0 m	9.1° 9.1°	CP-3000	slightly brownish green
3,200	missed			
3,400	"			
3,600	"			
3,800	"			
4,000	"			

TABLE 14. Phytoplankton, CP-400, Willow Run flyover, 7 May 1970.
Distance offshore -- 400 feet; sampled at 4 inches depth
Secchi disc -- 1.0 m
Water temperature -- 9.9°C
Water color -- greenish brown

Organism	Number of Colonies	Cells/liter
Cyclotella		2,279,795
Melosira spp.	1,085,175	7,006,335
Ankistrodesmus falcatus		341,320
Chlamydomonas spp.		137,270
Mallomonas spp.		64,925
Cryptomonas spp.		29,680
Dictyosphaerium pulchellum		24,115
Nitzschia acicularis		89,040
Oocystis submarina		1,855
Synedra ostenfeldii		96,460
Synedra ulna		25,970
Synedra filiformis		89,040
Synedra acus		9,275
Synedra delicatissima		31,535
Tabellaria fenestrata	37,100	287,525
Dinobryon divergens		20,405
Oscillatoria spp.		29,680
Nitzschia spp.		22,260
Nitzschia sp. 2		11,130
Surirella sp.		1,855
Pinnularia sp.		5,565
Achnanthes sp.		1,855
Gomphonema sp.		5,565
Navicula spp.		14,840
Asterionella formosa	16,695	79,765
Asterionella bleakeleyi	1,855	7,420
Scenedesmus quadricauda		5,565
Closteriopsis longissima		3,710
Fragilaria crotonensis	83,475	651,105
Stephanodiscus niagarae		5,565
Synedra ulna v. danica		7,420
Cocconeis sp.		1,855
Diatoma vulgare		1,855
Fragilaria intermedia	5,565	38,955
Synedra sp.		9,275
Quadrigula lacustris		1,855
Oocystis sp.		3,710

TABLE 15. Phytoplankton, CP-800, Willow Run flyover, 7 May 1970.
Distance offshore -- 800 feet; sampled at 4 inches depth
Secchi disc -- 1.6 m
Water temperature -- 9.1°C
Water color -- brownish-green

Organism	Number of Colonies	Cells/liter
Cyclotella spp.		3,031,070
Melosira granulata	118,720	808,780
Melosira granulata v. angustissima	14,840	140,980
Melosira binderana	122,430	467,430
Dictyosphaerium pulchellum		18,550
Peridinium spp.		22,260
Oocystis submarina		3,710
Ankistrodesmus falcatus		448,910
Chlamydomonas spp.		578,760
Cryptomonas spp.		55,650
Oscillatoria spp.		107,590
Mallomonas spp.		81,620
Nitzschia acicularis		103,880
Fragilaria crotonensis	107,590	931,210
Fragilaria intermedia	18,550	81,620
Fragilaria capucina	3,710	51,940
Synedra ulna v. danica		7,420
Pinnularia sp.		3,710
Closterium sp.		11,130
Nitzschia spp.		22,260
Synedra spp.		51,940
Navicula sp.		18,550
Dinobryon divergens		66,780
Asterionella formosa	22,260	96,460
Tabellaria fenestrata	44,520	322,770
Synedra filiformis		89,040
Stephanodiscus niagarae		3,710
Ophiocytium sp.		3,710
Synedra ulna		59,360
Synedra acus		14,840
Synedra ostenfeldii		7,420

TABLE 16. Phytoplankton, CP-1600, Willow Run flyover, 7 May 1970.
Distance offshore -- 1,600 feet; sampled at 4 inches depth
Secchi disc -- 1.8 m
Water temperature -- 8.5°C
Water color -- very slightly brownish-green

Organism	Number of Colonies	Cells/liter
Cyclotella spp.		912,660
Cryptomonas spp.		14,840
Chlamydomonas spp.		161,385
Ankistrodesmus falcatus		194,775
Phormidium spp.		22,260
Dinobryon divergens		24,115
Oocystis sp.		3,710
Mallomonas sp.		9,275
Stephanodiscus niagarae		1,855
Oscillatoria sp.		1,855
Scenedesmus quadricauda		1,855
Melosira islandica	79,769	330,190
Melosira granulata	5,565	33,390
Fragilaria crotonensis		209,615
Synedra ulna		3,710
Tabellaria fenestrata		115,010
Fragilaria capucina		31,535
Synedra ulna v. danica		20,405
Nitzschia spp.		25,970
Fragilaria intermedia	11,130	33,390
Dictyosphaerium pulchellum		5,565
Peridinium sp.		3,710
Gloeocystis sp.		1,855
Melosira granulata v. angustissima	3,710	9,275
Navicula sp.		3,710

TABLE 17. Phytoplankton, CP-3000, Willow Run flyover, 7 May 1970.
Distance offshore -- 3,000 feet; sampled at 4 inches depth
Secchi disc -- 2.0 m
Water temperature -- 9.1°C
Water color -- slightly brownish-green

Organism	Number of Colonies	Cells/liter
Closteriopsis longissima		5,565
Closterium aciculare		1,855
Scenedesmus abundans		1,855
Chlamydomonas spp.		393,260
Cyclotella spp.		1,650,950
Ankistrodesmus falcatus		213,325
Cryptomonas spp.		46,375
Peridinium spp.		25,970
Dinobryon divergens		42,665
Oscillatoria spp.		25,970
Mallomonas spp.		35,245
Quadrigula chodatii		3,710
Gomphosphaeria lacustris		3,710
Dictyosphaerium pulchellum		16,695
Melosira granulata	53,795	320,915
Melosira granulata v. angustissima	9,275	50,085
Melosira binderana	63,925	280,105
Nitzschia acicularis		35,245
Nitzschia sp. 1		24,115
Nitzschia sp. 2		3,710
Tabellaria fenestrata	14,840	230,020
Synedra acus		7,420
Synedra filiformis		66,780
Synedra ostenfeldii		35,245
Synedra ulna		7,420
Synedra ulna v. danica		5,565
Asterionella formosa	20,405	111,300
Navicula sp.		5,565
Diatoma tenue v. elongatum		3,710
Fragilaria intermedia	9,275	44,520
Fragilaria crotonensis	59,360	217,035
Scenedesmus quadrigula		3,710
Kirchneriella elongata		1,855
Cosmarium sp.		1,855
Melosira varians	1,855	11,130
Synedra ulna v. chaseana		1,855
Synedra delicatissima		7,420

This was a marginal day, with wind out of the southwest at 20 mph and wave and surf conditions according; our sampling was in the period 1500 to 1630 when we believed the plane to be coming.

As shown in Table 13, the water colors on this day indicate the presence of four slightly differing water masses each of which is a blend of the two water masses characteristic of the region: green offshore lake water, and the brown effluent from the St. Joseph River.

Analyses of phytoplankton samples representative of each of the four apparent water masses also indicate blending of offshore water and river water.

The results suggest that a recent storm had fairly well mixed the area and that the general lake circulation had not yet reestablished the typical condition of more distinctly different water masses.

B. SURVEYS OF EXISTING WARM WATER PLUMES

<u>The Bagged-Water Technique for Testing In Situ Response of Planktonic Organisms to Waste Heat of Existing Generating Plants</u>. During the winter of 1969-70 Drs. Ayers and Arnold worked extensively on the problem of tests adequate to investigate the observed fact that plumes of warm cooling water from existing electric generating plants are not supporting nuisance blooms of planktonic algae as a result of their discharged excess heat.

After several sorts of experiments had been considered and discarded, it was decided to try an experimental technique that appeared capable of testing the combined effects of passage through a generating plant <u>and</u> the effects of waste heat in the plant plume. The technique is simple, direct, and allows separate evaluation of the effects of 1) waste heat alone, 2) passage through the plant without waste heat effects of the plume, and 3) the combined effects

of passage through the plant plus existence in the waste heat of the plume during the plume's existence. Its weakness lies in item 2) where we are unable to separate mere physical mauling in passage through the plant from the abrupt addition of temperature during passage through the plant's condensers. The following summarizes the sampling, exposure, and effects-sought aspects of the technique.

Water source	Water exposed to	Effect(s) being sought
Intake	Ambient temperature	Control, no heat effects, no plant passage
Outfall	Ambient temperature	Passage through plant only
Intake	Plume temperature	Heat of plume only
Outfall	Plume temperature	Plant passage plus plume heat

Clear plastic bags are used and the bagged water is subsampled for analyses at the end of the experiment. Exposure to ambient temperature is accomplished by anchoring bags well away from the discharge water plume. Exposure to plume temperatures is by filling the bags at the outfall and allowing them to float nearly submerged down the length of the plume to ambient or near-ambient temperature. The experiment is terminated at this point and the bags anchored in ambient temperature are subsampled, after which the free bags are subsampled.

On 20 June 1970 in the plume of the NIPSCO Bailly plant, the technique was tested for debugging. The day was dark with hazy sun, changing later to overcast with light rain; wind was out of the south southeast at 5-8 knots early in the day and diminished to 2-5 knots later in the day. Air temperature at one foot above the water surface on the north side of the Bailly intake crib north of the outfall flume was 19.5°C at 1045; at 1110 the on-foot air temperature at the mouth of Bailly's outfall flume was 20.5°C. Surface water at the north side of the intake crib was 18.0° and that in the mouth of the outfall was 25.0° at the times given above. All temperatures were taken with a mercury thermometer.

On this day Bailly was generating 522,500 KW and cooling water pumpage was 150,000 gpm. The plant's discharge-water plume was moving in a generally northeast direction about midway between the intake crib and the east-trending beachline. There was no thermal evidence at the crib that any plume water was being drawn to the crib in recycling.

Clear plastic bags of about 115 liters capacity were employed in the experiments. Working from a small boat, on the north side of the intake crib two plastic bags were laid on the water and each was filled with 100 liters of intake surface water by dipping with a measured bucket; the necks of the bags were tied securely and the bags were anchored at the north side of the intake crib. Filling and emptying of the bags by dipping with the bucket were necessitated by the fact that the bags were not strong enough to hold their burden when out of water. At the north side of the intake crib a nominally 30-gallon plastic garbage can in the boat was filled with intake water and the boat moved to the outfall flume where it tied up to the center of the flume's ironwork structure. Here the contents of the garbage can were put by bucket into two plastic bags which received 40 and 54 liters respectively. The bag mouths were tied, and the bags tied together; they were then released and allowed to float down the plant's effluent plume. The bags were followed, and water temperatures measured, until they arrived in temperature less than 1°C different than intake temperature. At this point the boat returned to the anchored bags of intake water, sampled them at 1125, returned the samples to the ship for processing, and went to sample the bags floating in the plume. By this time these bags were in ambient temperature; they were sampled at 1140 and the samples returned to the ship for processing.

After a short lunch break the small boat returned to the mouth of the outfall flume where at 1325 it filled two bags with 80 liters each of outfall water, tied their mouths, tied them together, and allowed them to float down

the plume. The plastic garbage can was then filled with outfall water and taken to the north side of the intake crib where two bags were filled with 50 liters each of outfall water at 1335, tied off, and anchored in ambient temperature in the same place as the previously taken bags of intake water. The boat then spent about 20 minutes in gassing-up and following the floating bags into ambient temperature. These bags were sampled at 1355 and the samples returned to the ship for processing. The boat then went to and sampled at 1410 the bags of outfall water anchored in ambient temperature at the north side of the intake crib, and returned the samples to the ship.

Each bag was designated by 1) the source of its water, I for intake water and O for outfall water, and 2) by the exposure to which the water was subjected, A for exposure to ambient temperature and P for the varying temperatures encountered during a drift down the length of the plant's cooling water plume. Duplicated bags were given suffixed numbers such as IP-1 and IP-2. Subsamples taken from the several bags are designated by the bag designations.

The bags were sampled at the end of the experiments for total and coliform bacteria, dissolved oxygen, phytoplankton, and zooplankton.

Bacteria were sampled by the Millipore nutrient-pad method using nutrient media for both the coliform and total bacteria. Dissolved oxygen was determined by the Hach engineer's portable laboratory method. Phytoplankton were sampled by dipping a liter bottle full of water and preserving with Utermohl's iodine solution. Zooplankton were sampled by bucketing all the remaining water of the bag through a #5 plankton net; zooplankton samples were not preserved, but returned fresh to the ship and examined in a projection microscope for activity vs moribundity (live vs apparently dead) after which they were preserved in buffered formalin.

The experiments at Bailly were primarily aimed at determining the feasibility of the technique, which they have done. They indicated some needed

improvements in methods. They also produced some preliminary results which are given below and discussed.

Following the generalized instructions of the Millipore bacterial method, the sampling gear were well rinsed in the water to be sampled and 100 ml of water put through the nutrient pad culture dish for each of total bacteria and coliforms. Inocculated with the specified nutrient media, the culture dishes were incubated at 35°C for 18-24 hours and the resultant bacterial colonies counted under a binocular microscope at about 7X magnification. It is now evident that 100 ml subsamples are too large to be used in the inshore waters of southern Lake Michigan. After 18 hours of incubation the filter pads for total bacteria were so overgrown that colonies merged and counting was impossible. This was not true for the coliform pads, though the numbers of colonies to be counted were excessive. It appears that 25 ml will be a sufficient subsample in the inshore waters of Lake Michigan. Several culture dishes were discarded after it was discovered that a loose fitting on the syringe-pump of the Millipore gear was passing air bubbles whose air-borne bacteria would be deposited on the filter. The usable results are given in the following table. No conclusions are drawn from these results, other than that the method is usable.

Sample	Coliforms/ml	Total bacteria/ml
IA-2-C-100	460	-------
IA-2-T-100	---	Too overgrown to count
OA-2-C-100	291	-------
OA-2-T-100	---	Too overgrown to count
OP-2-C-100	0	-------
OP-2-T-100	---	Too overgrown to count

The Hach-kit dissolved oxygen method is adjudged to be too insensitive for the needs of this type of experiment. In all the samples the dissolved oxygen measured 9 mg/1, or 9 ppm. It will be necessary to return to a full-fledged Winkler oxygen determination to ascertain whether passage through a

generating plant results in change of DO.

The experimental results for phytoplankton showed the bagged-water technique to be feasible, but they also indicate that the patchy distribution of plankton in the lake is not smoothed out by passage through a plant.

The phytoplankton results are summarized in Table 18. The table includes all the species that were common to the six experimental bags. Each pair of duplicate bags (OA-1, OA-2 and OP-1, OP-2) was filled in succession in a few minutes and water for the IA and IP bags was taken at the intake within a few minutes. The variation in counts within these paired samples is considerably greater than the error of our method (about plus or minus 25%, but still in process of being refined) and is taken to indicate short-term patchiness of the plankton populations. The degrees of count variation between the three sets of paired samples are about the same, and also appear to show patchiness of the population. Effects of waste heat on the phytoplankton types or numbers were, if present, small and masked by the population patchiness.

In future experiments all bags will be run in duplicate, phytoplankton subsamples from each bag will be in duplicate, and from each subsample duplicate aliquots will be counted. This will give eight values with which to evaluate each of the four parts of each total plume experiment. This seems to be a workable compromise between statistical desirability and the counting of a prohibitive number of samples.

The results of the zooplankton experiments, also, showed the bagged-water techniques to be feasible; they, also, indicated patchiness of plankton population; and they, also, indicated some areas of needed improvement.

The zooplankton results are summarized in Table 19.

The variations in zooplankter numbers between duplicate bags indicate short-term patchiness of the population; though the bags were filled one after the other, in a few minutes the variations are present. Since the total bag

TABLE 18. Phytoplankton -- Summary table of bag experiments at Bailly, 20 June 1970. Thousands of cells per liter.

Genera and species	Experimental bags							
	IA	IP	OA-1	OA-2	OA mean	OP-1	OP-2	OP mean
DIATOMS								
Rhizosolenia eriensis	85	53	55	115	85	155	105	130
Melosira granulata	96	76	111	74	94.5	37	131	84
Melosira binderana	59	191	211	89	150	185	133	159
Tabellaria fenestrata	834	849	916	1,825	1,370.5	931	1,022	976.5
Fragilaria crotonensis	1,046	1,064	645	912	778.5	1,220	1,185	1,202.5
Asterionella formosa	44	53	22	59	40.5	11	90	50.5
Synedra ulna	37	31	29	63	46	25	31	28
Synedra ostenfeldii	59	50	7	89	48	77	50	63.5
Synedra ulna v. danica	11	18	25	18	21.5	37	18	27.5
Synedra filiformis	122	116	178	178	178	96	92	94
GREENS								
Dinobryon divergens	534	510	348	348	348	434	380	407
Ankistrodesmus falcatus	3?	16	11	22	16.5	14	18	16
FLAGELLATES								
Chlamydomonas spp.	96	51	66	55	60.5	129	64	96.5
Cryptomonas spp.	96	89	81	40	60.5	103	76	89.5
Peridinium spp.	14	22	14	22	18	3	9	6
Mallomonas spp.	11	31	29	11	20	55	25	40
BLUE-GREENS								
Oscillatoria spp.	25	29	18	25	26.5	11	16	13.5

TABLE 19. Zooplankton -- Summary table of bag experiments at Bailly, 20 June 1970.

Bag	Time filled	Time emptied	Elapsed time	Water volume	Zooplankton/l Alive	Zooplankton/l Dead	Live/Dead Ratio/l	Means of Ratios
IA-1	1,055	1,125	30 min	100 l	0.50	0.45	1.11	1.03
IA-2	"	"	"	100 l	0.77	0.82	0.94	
IP-1	1,113	1,140	28 min	40 l	0.40	1.00	0.40	0.45
IP-2	"	"	"	54 l	0.28	0.56	0.50	
OP-1	1,325	1,355	30 min	80 l	0.96	1.13	0.85	0.74
OP-2	"	"	"	80 l	0.64	1.03	0.62	
OA-1	1,335	1,410	35 min	50 l	0.88	1.70	0.52	0.57
OA-2	"	"	"	50 l	1.42	2.32	0.61	

contents were put through the zooplankton net and the entire collection counted, there is no question of the reproducibility of aliquot counts involved.

The zooplankton net used was a #5 mesh which did not catch the smaller zooplankters; the proportions of live and dead represent the condition among the larger, more damageable, zooplankters.

The highest ratio of live to dead zooplankters was found in the bags of intake water retained at ambient temperature (IA bags). Plankters in these bags had been subjected only to natural in-lake damage and that attributable to bucket-filling of the bags.

The smallest live/dead ratios were found in the bags of intake water drifted through the plume (IP bags). Plankters in these bags had been subjected to natural damage, bag-filling damage, and plume temperatures; that fewer survived this treatment than survived passage through the plant (OP bags) is unrealistic. It is attributed to too small zooplankton numbers in the bagged water volumes used. Larger bags containing more zooplankton should provide more reliable counts.

Passage through the plant, with and without the effects of plume heat, produced intermediate live/dead ratios that are probably not significantly different.

The major improvements that these experiments indicate are: 1) the use of considerably larger water-bags, and 2) the use of a #10 mesh net for zooplankton collections. The necessity for prompt microscopic examinations of fresh zooplankton collections mitigates against greater replication of samples.

The condensers at Bailly were chlorinated at 1200 on 20 June 1970. Reference to the times included in the zooplankton summary table will show that our outfall water samples were obtained 1.5 hours after the chlorination.

The elapsed time column of that table indicates that about 30 minutes were required for water from the outfall mouth to pass through the plume, and if five minutes are assumed as the time for passage from condenser to outfall mouth, the chlorine remnants must have passed out of the outfall about an hour before our 1325 samples were taken. It is extremely unlikely that any effect of chlorination is contained in our bacterial, phytoplankton, or zooplankton results.

Studies of the DuPont Chemical Company Submerged Outfall at Montague, Michigan. About 12 miles north of Muskegon, Mich., there is a small drowned river valley called White Lake which opens into Lake Michigan. About 5 miles inland from Lake Michigan the two towns of Montague (on the north) and Whitehall (on the south) lie on opposite sides of the White River at the head of White Lake. The names of the towns and of White Lake are used with a confusing amount of interchangeability.

In Montague the DuPont Chemical Company runs a chemical plant which has an outfall for the discharge of warmed water and some waste chemicals into Lake Michigan. The plant effluent leaves the plant at 26.7°C, travels about

two miles overland in an exposed 2-foot-diameter pipe before going underground at the lakeward edge of the sand dunes and into a pipe leading to the submerged diffusing chamber. From the diffusing chamber the effluent is discharged at 7500 gpm through three nozzles spanning 90° of arc between northwest and southwest. Each nozzle is directed upward from the lake bottom at 45°. The outfall complex is at 14 feet of depth on Lake Michigan low-water datum.

These data were very kindly provided by Mr. Earl Watt of the Company. They are very much appreciated, and our thanks to Mr. Watt are here formally tendered.

On 23 October 1970 the temperature of the effluent water in the pipe was measured through an opening in the pipe just before it went underground at the lake edge. It was 20.7°C; the air temperature was 13.5°C; in its overland extent the pipe had disposed of 6.0°C of temperature on this morning.

On the lake the wind was southeast at 5-10 mph; there were no large waves, but long swells averaging about 3 feet in height were running from south to north.

The outfall plume was located visually through a slight discoloration of the water and a modification of surface roughness. Directly over the outfall complex the water temperature was 12.7°C.

A parallelogram of measurement stations, arranged in lines parallel to and perpendicular to the trend of the shoreline, was occupied; these stations are shown in Figure 3. At each measurement station the ship was stopped and a partial vertical profile of temperature obtained from a thermistor chain of six YSI (Yellow Springs Instrument) Model 402 thermistors spaced one foot apart on a weighted line and read with a YSI Telethermometer Model 44. In the first lowering-position the thermistors sensed temperatures at 0, 1, 2, 3, 4, and 5 feet of depth; the whole chain was then lowered 6 feet and readings at 6, 7, 8, 9, 10, and 11 feet taken; usually the vertical soundings were stopped at

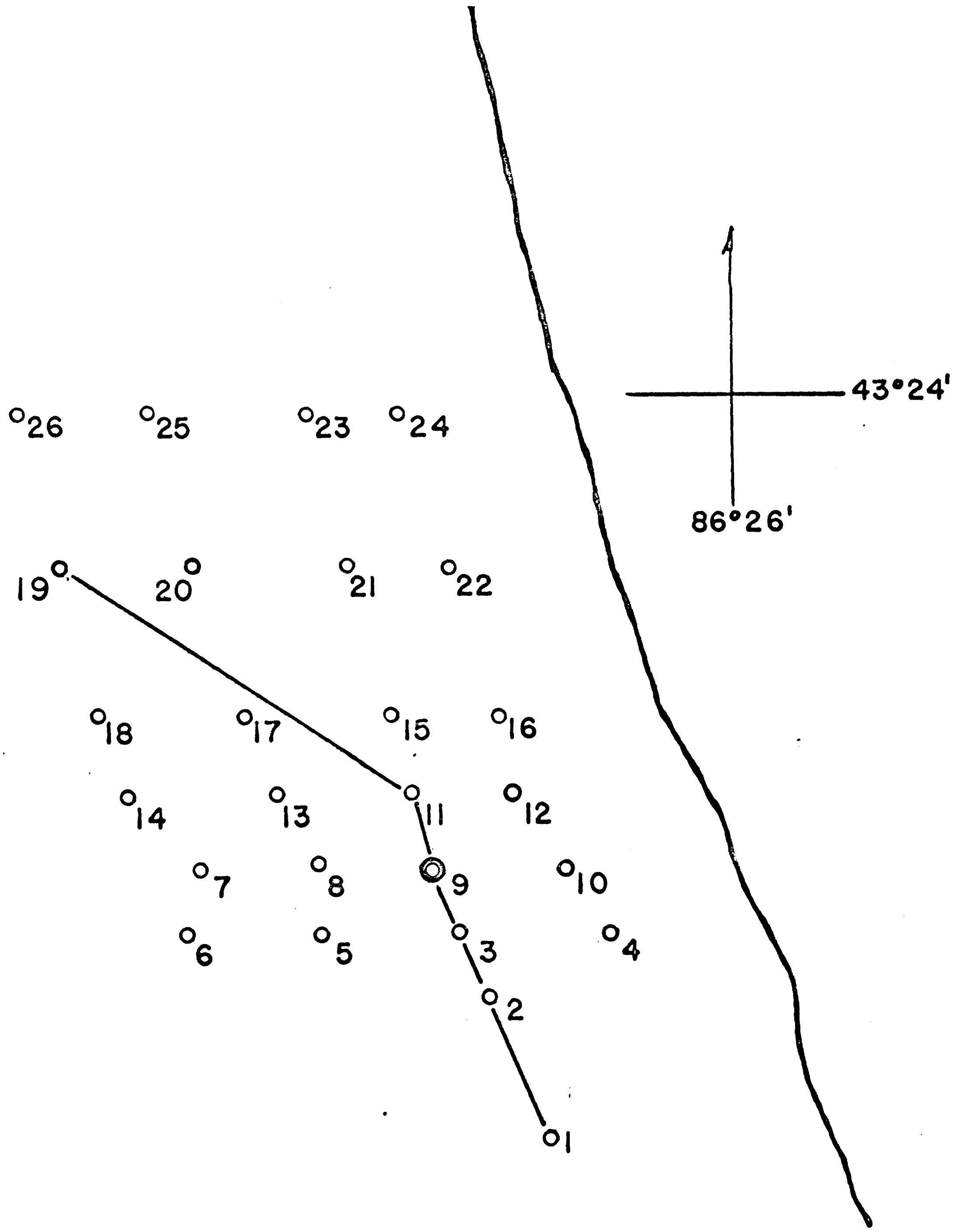

FIG. 3. Temperature stations, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. Line segments show the stations used in the vertical temperature profile. SE wind 5-10 mph.

11 feet because if more time was spent on station the ship's drift was sufficient to distort the grid of survey stations. In a few stations deeper soundings were taken, but in most the vertical temperature changes were encompassed in the top 11 feet of water.

The temperature results obtained are presented in Figures 4 through 13 and are tabulated in Table 20.

The outstanding characteristics of the DuPont plume on 23 October were a narrow rising column of warmed water which had steep temperature gradients on its east, south, and west sides and which tailed away downcurrent northwestward in the upper 2 feet with a small thin lens of warm water on the very surface at the most distant station (Station 19) in the plume.

Figures 4 through 12 present the observed horizontal distributions of temperature at one-foot intervals from the surface through 8 feet of depth; by this depth most isotherms were vertical. The prime cause for studying the DuPont plume was to obtain some indication of how the plume from the much larger submerged outfall of the Donald C. Cook Plant might behave, consequently the vertical section of temperatures shown in Figure 13 is probably of most direct interest. This section is drawn through Stations 1, 2, 9, 11, and 19 of the survey grid and is indicated by the line through these stations on the chart of station locations (Fig. 3). The section was drawn by plotting where isotherms in the foot-by-foot horizontal plots crossed the section line in the station location chart.

There are several things that need to be said regarding this figure. The figure has gross vertical exaggeration: the total length of the section is about 1.5 miles; the maximum water depth is about 30 feet; to draw it to scale is impossible.

Our thermistors were matched to within 0.1°C in the laboratory, and in the small temperature field encountered at the DuPont outfall we have used

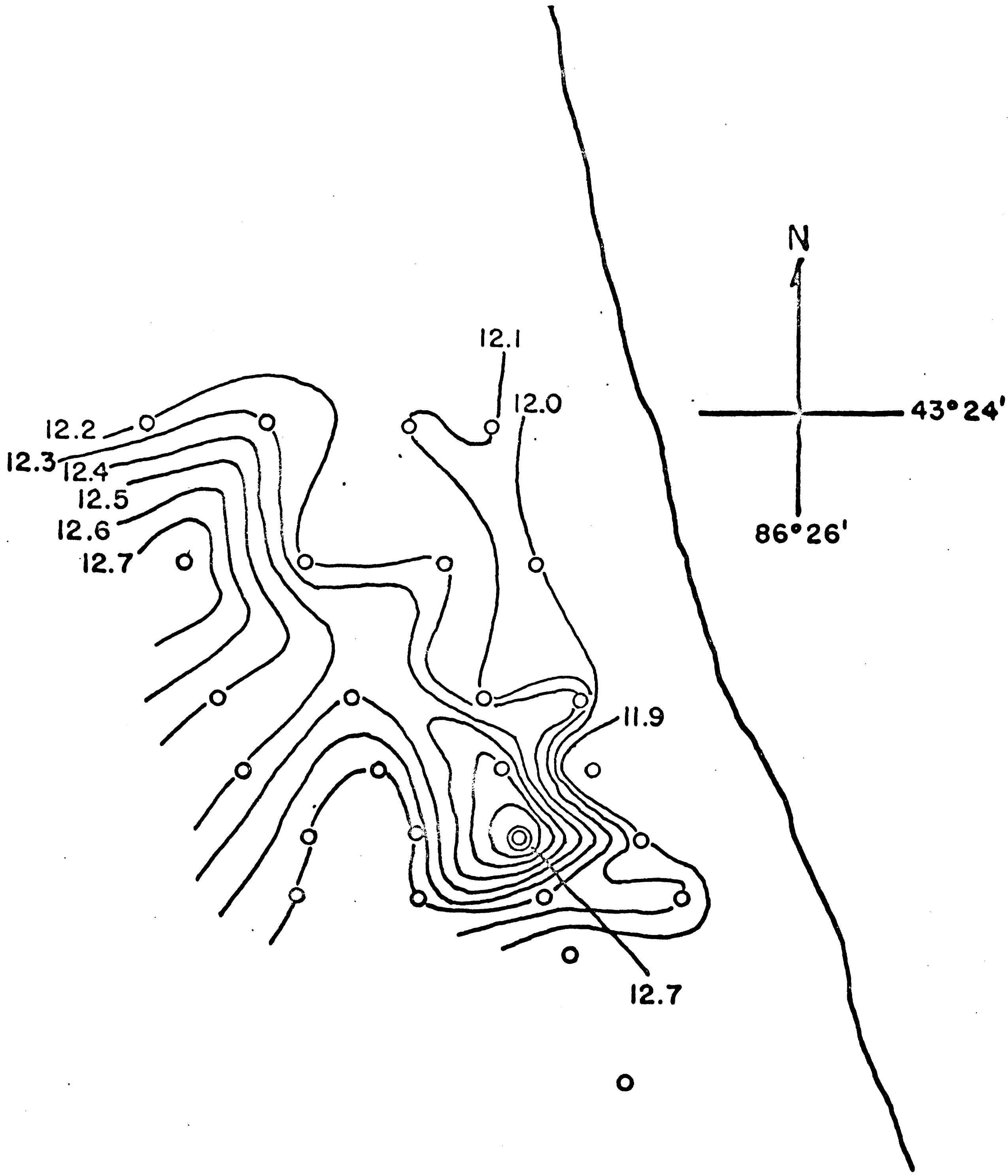

FIG. 4. Surface temperature distribution °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

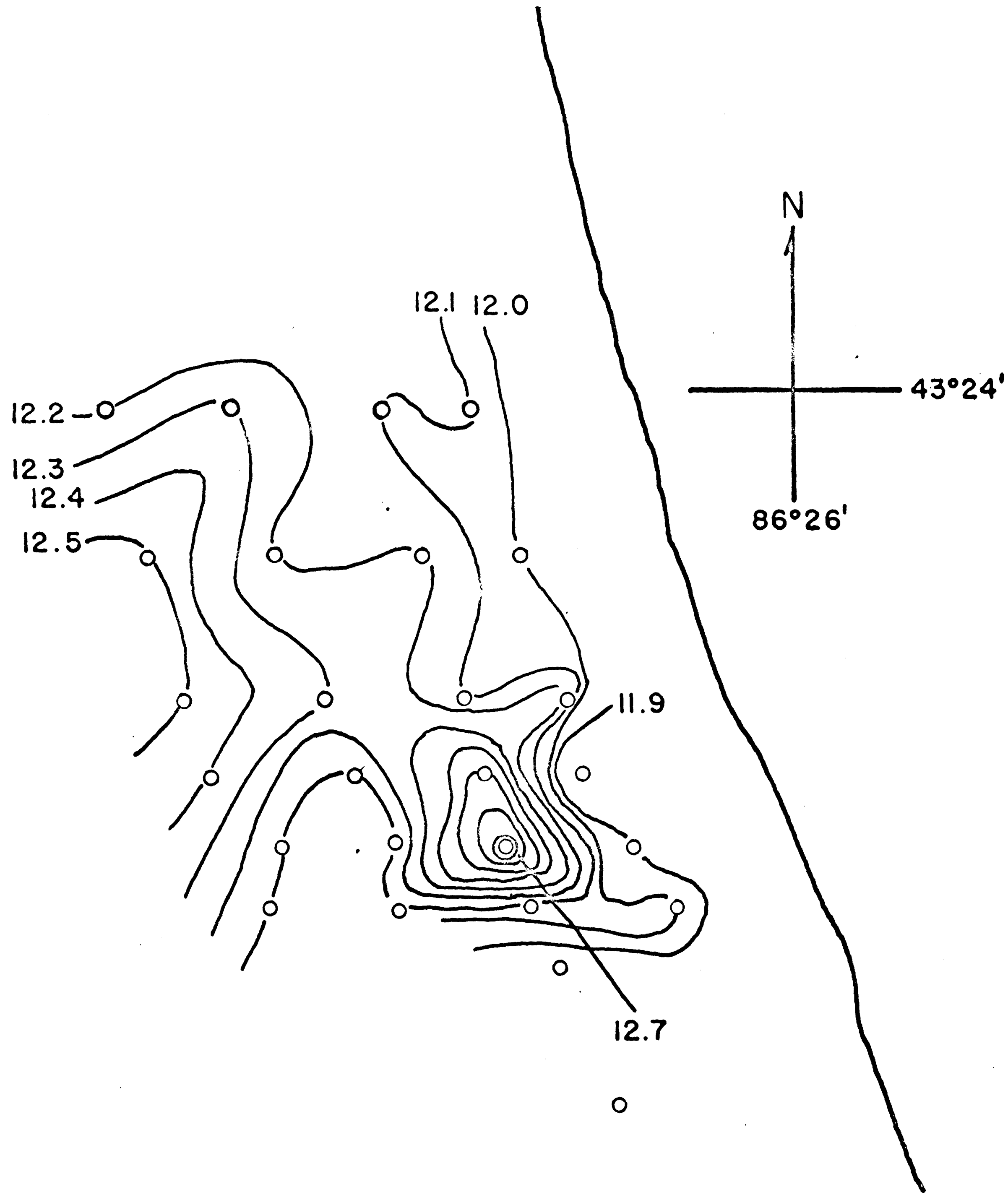

FIG. 5. Temperature distribution at 1 foot, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

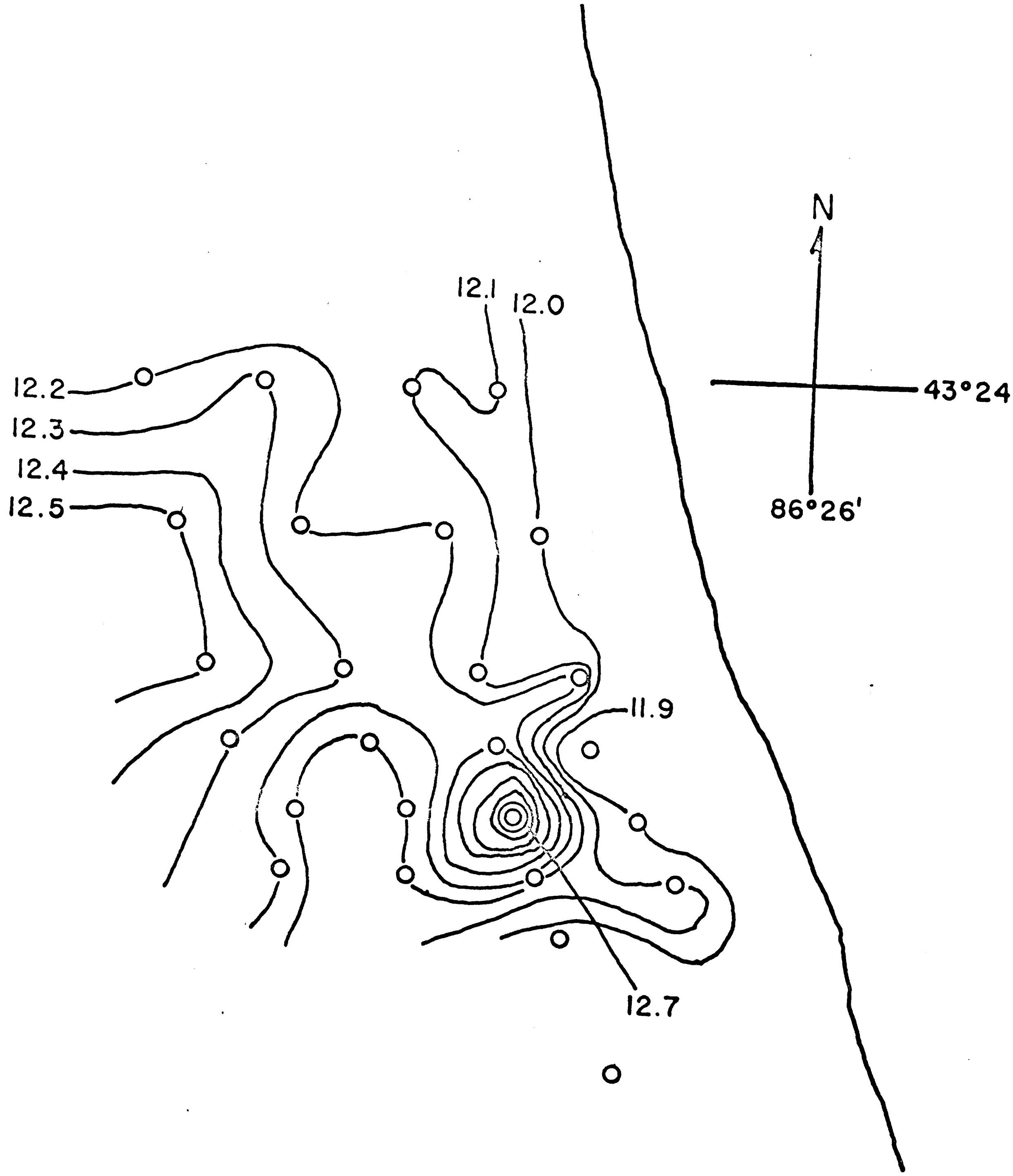

FIG. 6. Temperature distribution at 2 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

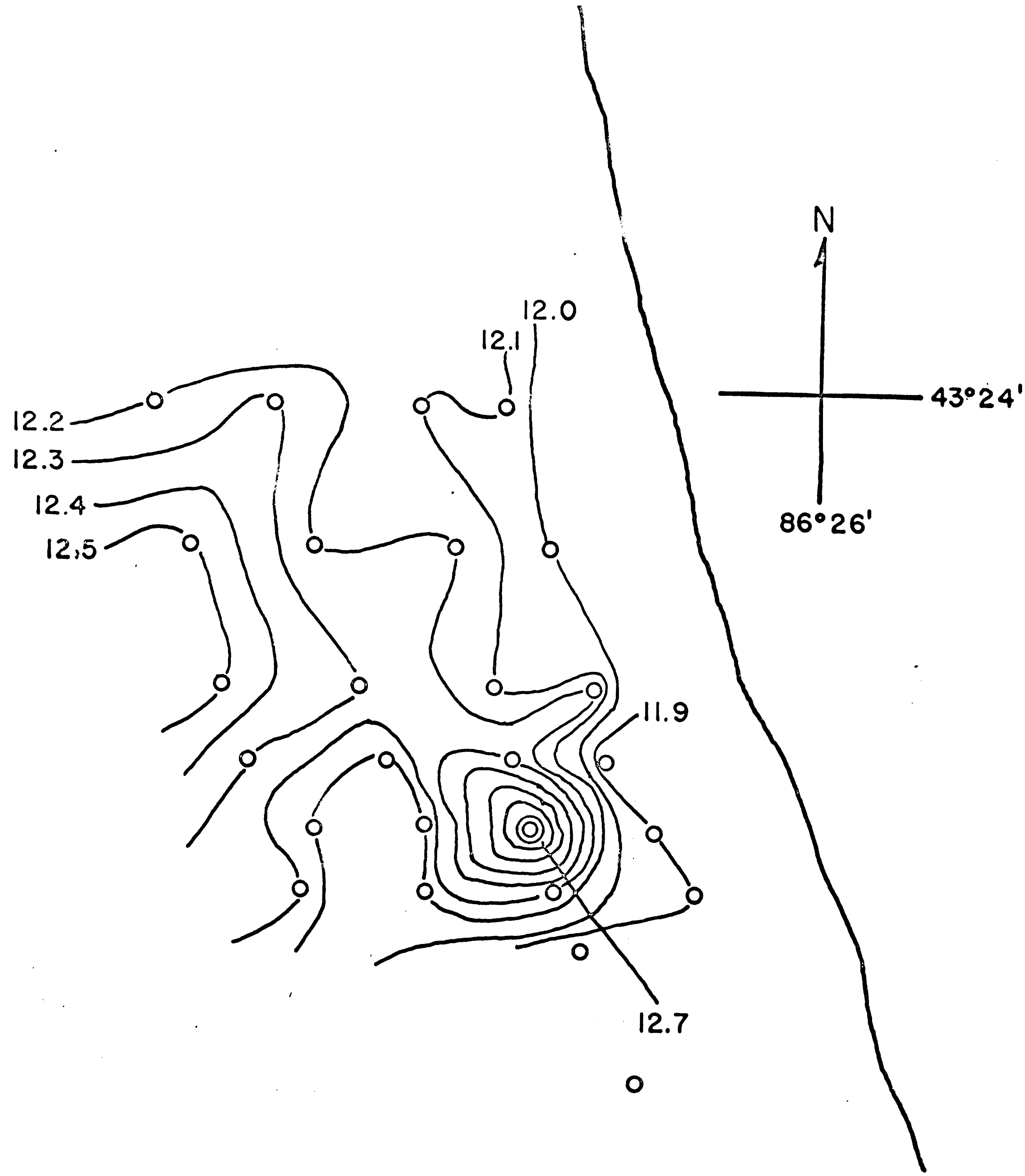

FIG. 7. Temperature distribution at 3 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

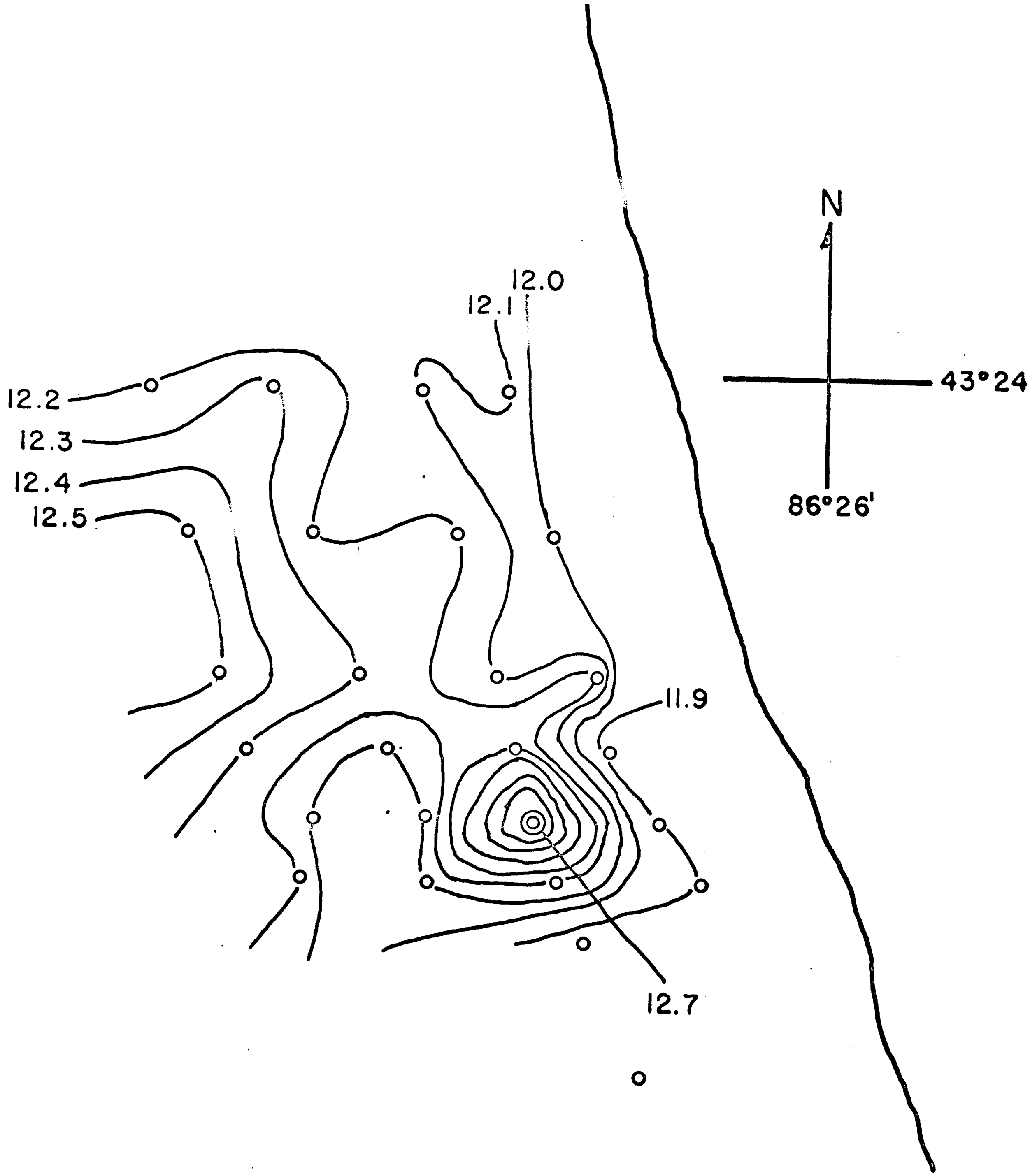

FIG. 8. Temperature distribution at 4 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

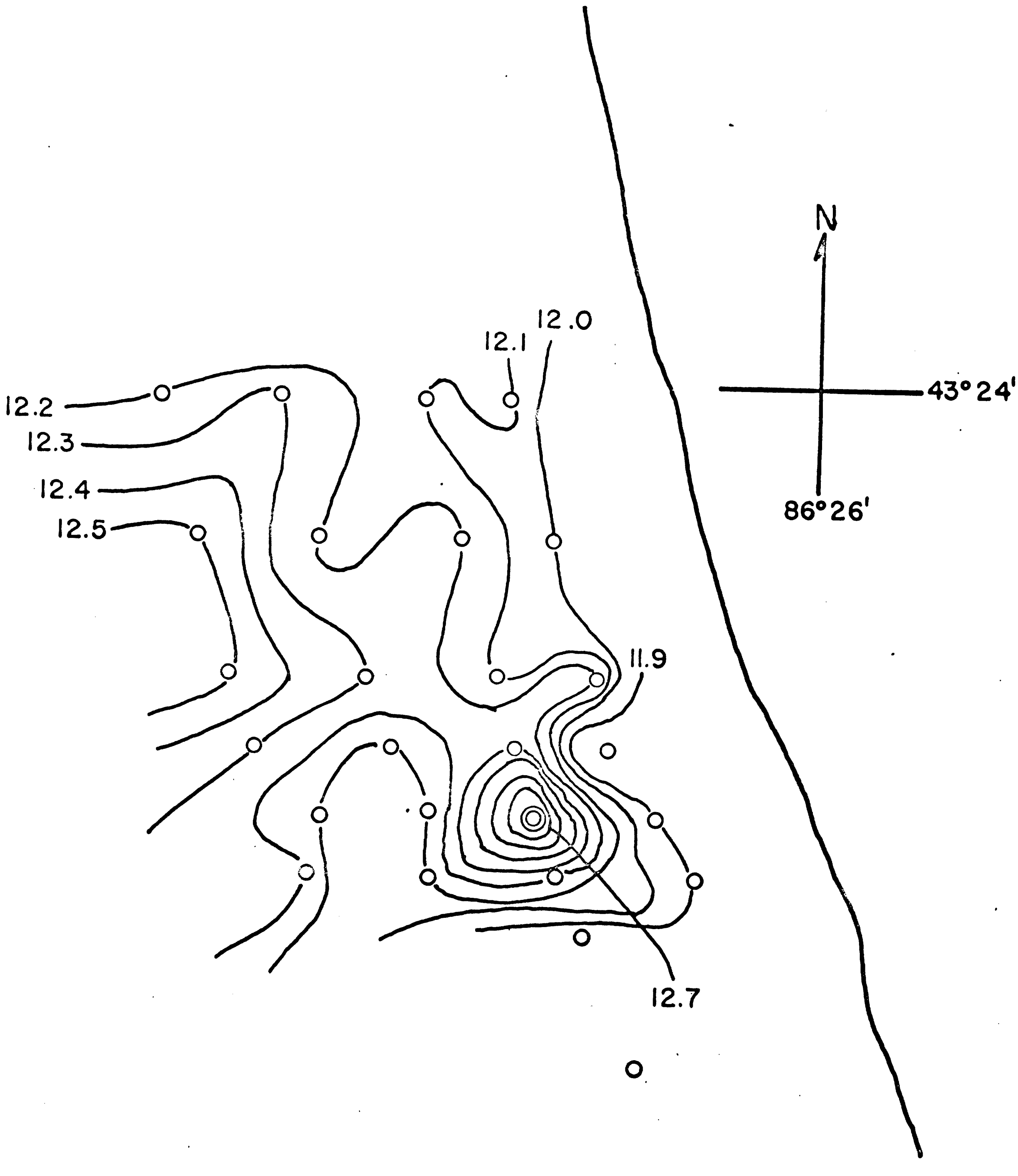

FIG. 9. Temperature distribution at 5 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

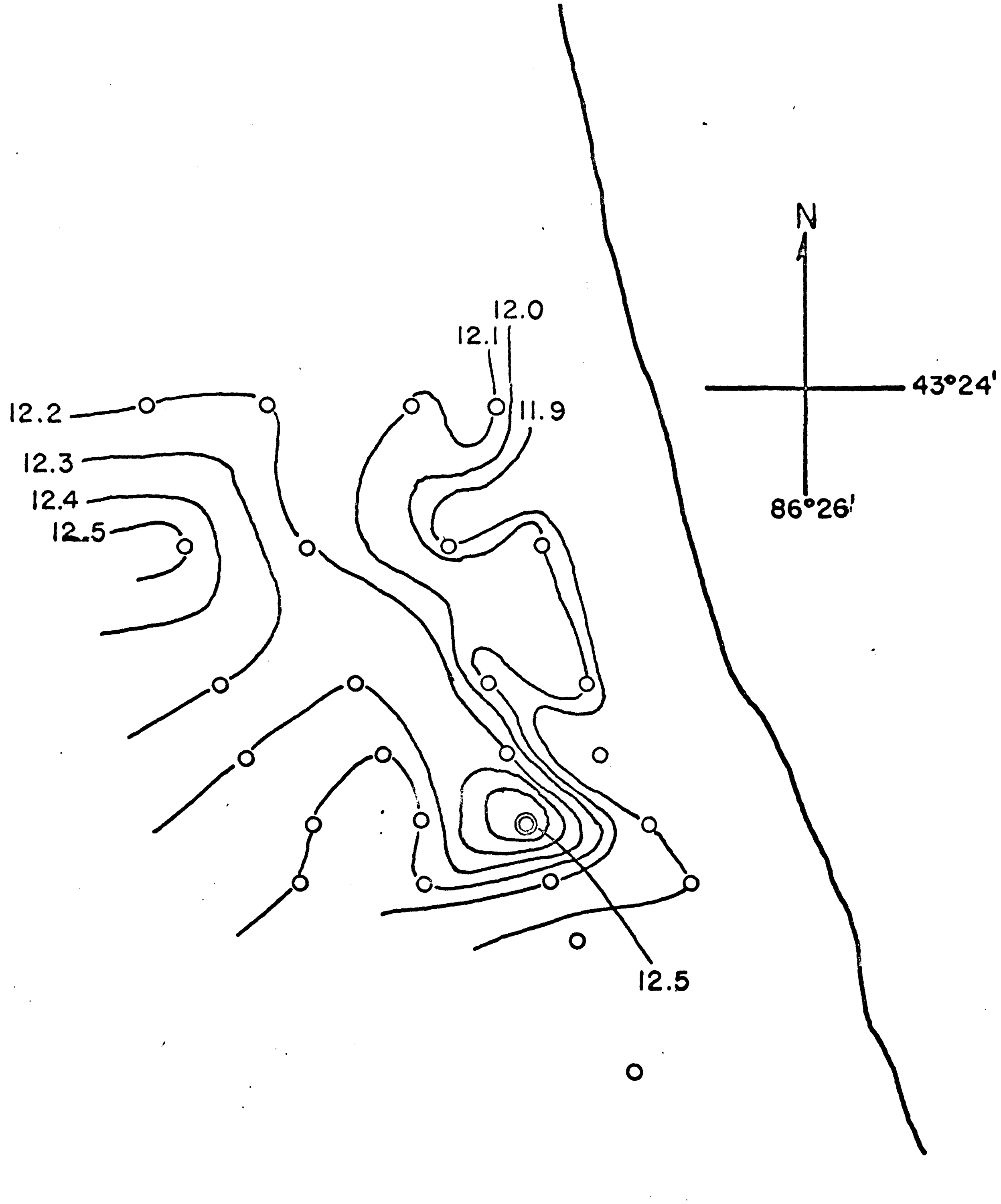

FIG. 10. Temperature distribution at 6 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

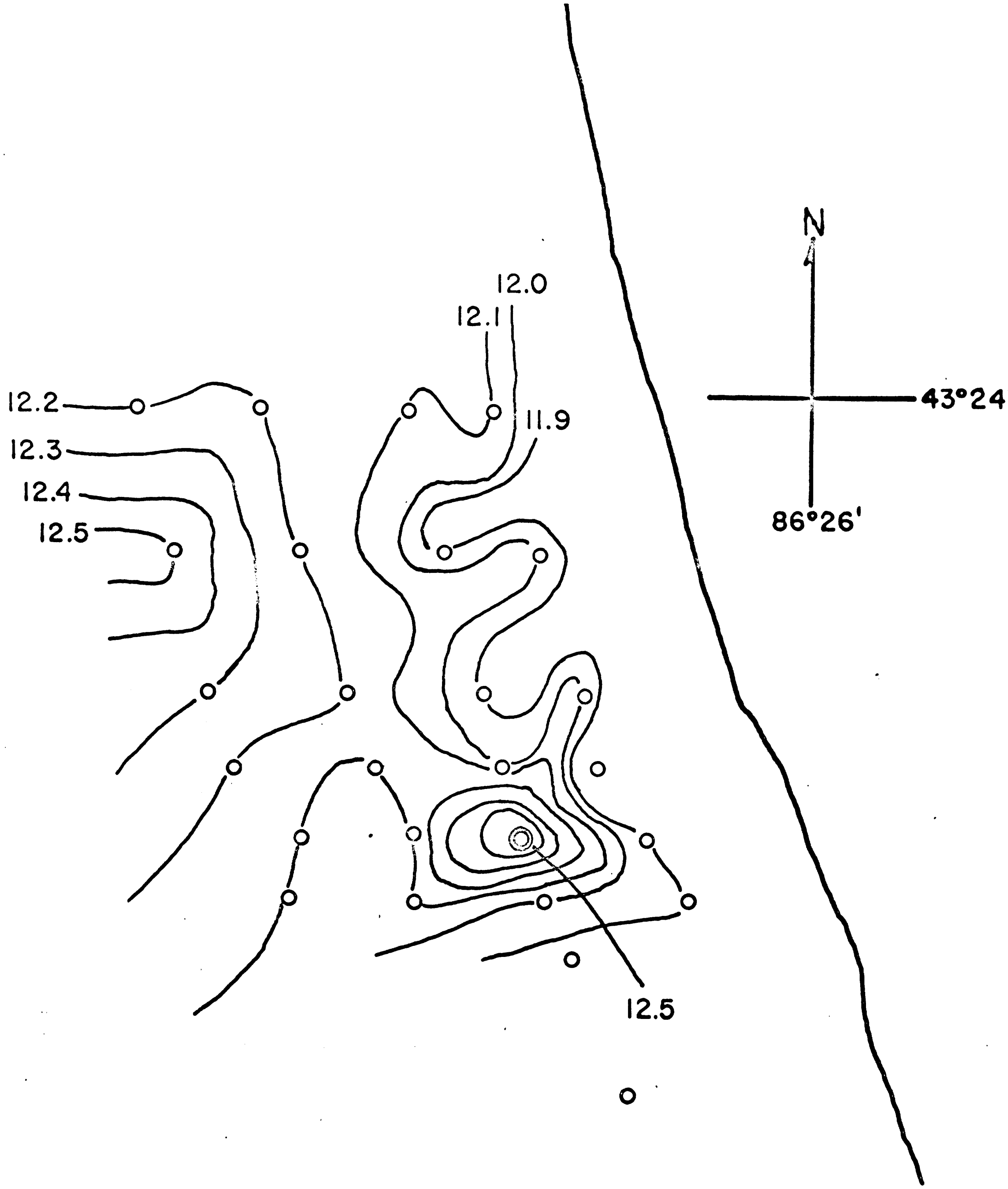

FIG. 11. Temperature distribution at 7 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

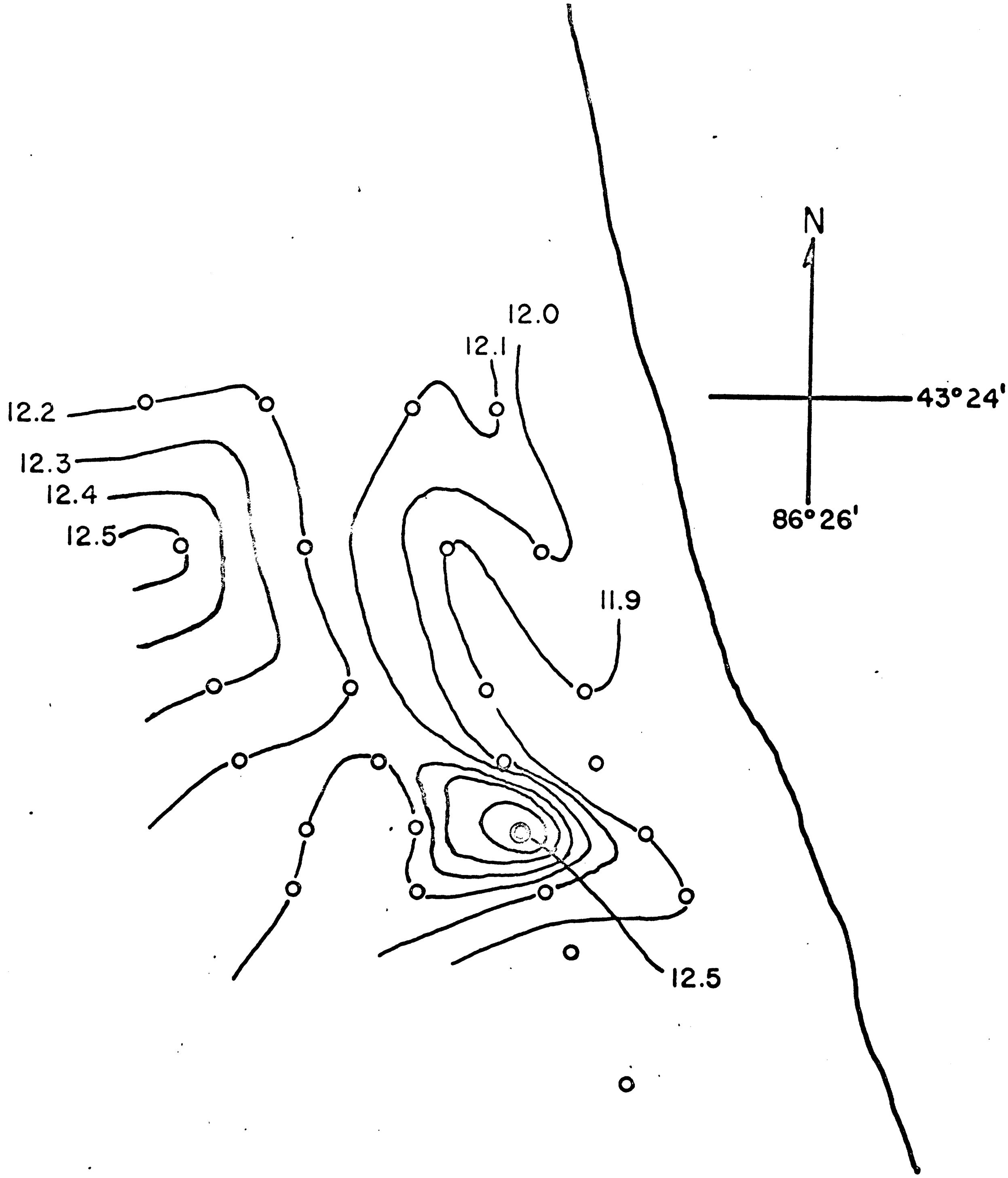

FIG. 12. Temperature distribution at 8 feet, °C, DuPont Chemical Co. plume survey, Montague, Mich., 23 October 1970. SE wind 5-10 mph.

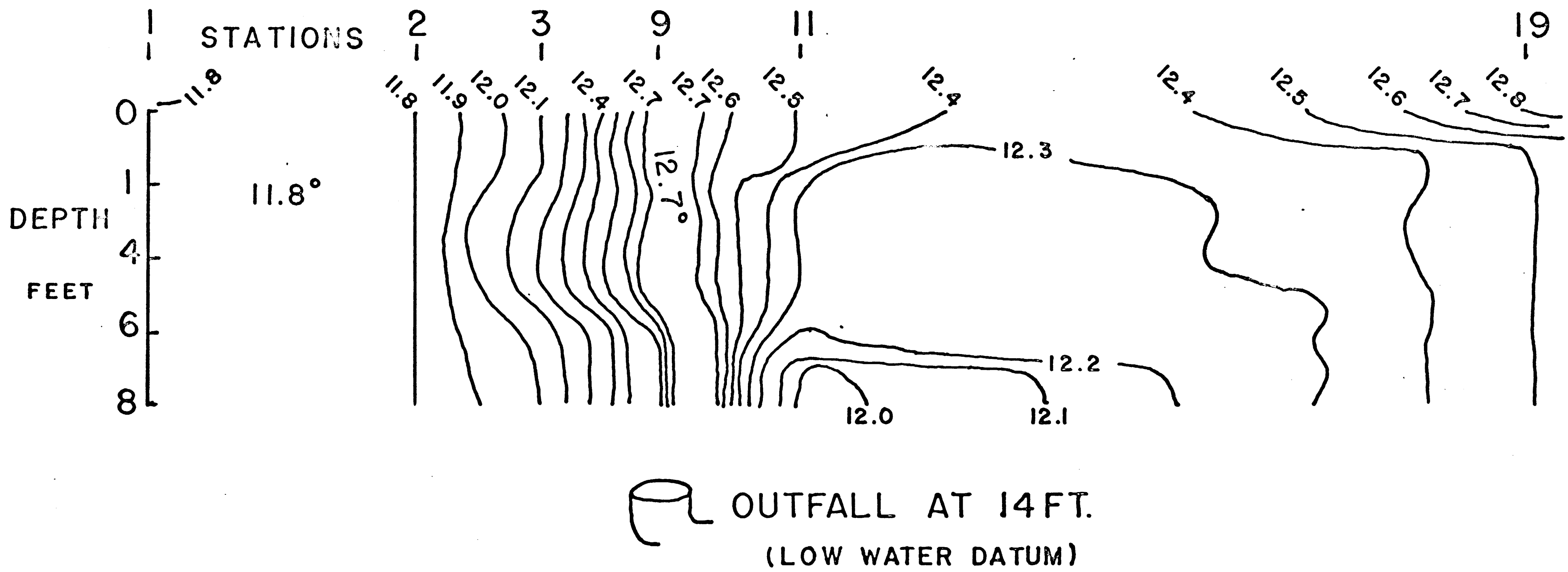

FIG. 13. Vertical distribution of temperature in a section across the outfall and down the plume; current from left to right DuPont Chemical Company plume study, 23 October 1970.

TABLE 20. Temperature Data, DuPont Outfall, Whitehall
23 October 1970

Station 1		Station 2		Station 3	
Surface	11.8°C	Surface	11.8°C	Surface	12.1°C
1 ft	11.8	1 ft	11.8	1 ft	12.1
2 ft	11.8	2 ft	11.8	2 ft	12.1
3 ft	11.8	3 ft	11.8	3 ft	12.2
4 ft	11.8	4 ft	11.8	4 ft	12.2
5 ft	11.8	5 ft	11.8	5 ft	12.2
6 ft	11.8	6 ft	11.8	6 ft	12.0
7 ft	11.8	7 ft	11.8	7 ft	12.0
8 ft	11.8	8 ft	11.8	8 ft	12.0
9 ft	11.8	9 ft	11.8	9 ft	12.0
10 ft	11.8	10 ft	11.8	10 ft	12.0
11 ft	11.8	11 ft	11.8	11 ft	12.0
12 ft	11.8				
13 ft	11.9				
14 ft	11.9				
15 ft	11.9				
16 ft	11.9				
17 ft	11.9				

Station 4		Station 5		Station 6	
Surface	12.0°C	Surface	12.1°C	Surface	12.1°C
1 ft	12.0	1 ft	12.1	1 ft	12.1
2 ft	12.0	2 ft	12.1	2 ft	12.2
3 ft	11.9	3 ft	12.1	3 ft	12.2
4 ft	11.9	4 ft	12.1	4 ft	12.2
5 ft	11.9	5 ft	12.1	5 ft	12.2
6 ft	11.9	6 ft	12.1	6 ft	12.1
7 ft	11.9	7 ft	12.1	7 ft	12.1
8 ft	11.9	8 ft	12.1	8 ft	12.1
9 ft	11.9	9 ft	12.1	9 ft	12.1
10 ft	11.9	10 ft	12.1	10 ft	12.1
11 ft	11.9	11 ft	12.1	11 ft	12.1

TABLE 20.(Cont.)

Station 7		Station 8		Station 9	
Surface	12.1°C	Surface	12.1°C	Surface	12.7°C
1 ft	12.1	1 ft	12.1	1 ft	12.7
2 ft	12.1	2 ft	12.1	2 ft	12.7
3 ft	12.1	3 ft	12.1	3 ft	12.7
4 ft	12.1	4 ft	12.1	4 ft	12.7
5 ft	12.1	5 ft	12.1	5 ft	12.7
6 ft	12.1	6 ft	12.1	6 ft	12.5
7 ft	12.1	7 ft	12.1	7 ft	12.5
8 ft	12.1	8 ft	12.1	8 ft	12.5
9 ft	12.1	9 ft	12.1	9 ft	12.5
10 ft	12.1	10 ft	12.1	10 ft	12.5
11 ft	12.1	11 ft	12.1	11 ft	12.5

Station 10		Station 11		Station 12	
Surface	11.9°C	Surface	12.5°C	Surface	11.5°C
1 ft	11.9	1 ft	12.5	1 ft	11.5
2 ft	11.9	2 ft	12.3	2 ft	11.5
3 ft	11.9	3 ft	12.3	3 ft	11.8
4 ft	11.9	4 ft	12.3	4 ft	11.8
5 ft	11.9	5 ft	12.3	5 ft	11.5
6 ft	11.9	6 ft	12.2	6 ft	11.5
7 ft	11.9	7 ft	12.0	7 ft	11.5
8 ft	11.9	8 ft	12.0	8 ft	11.5
9 ft	11.9	9 ft	12.0	9 ft	11.5
10 ft	11.9	10 ft	12.0	10 ft	11.5
11 ft	11.9	11 ft	12.0	11 ft	11.5

Station 13		Station 14		Station 15	
Surface	12.1°C	Surface	12.4°C	Surface	12.1°C
1 ft	12.1	1 ft	12.4	1 ft	12.1
2 ft	12.1	2 ft	12.3	2 ft	12.1
3 ft	12.1	3 ft	12.3	3 ft	12.1
4 ft	12.1	4 ft	12.3	4 ft	12.1
5 ft	12.1	5 ft	12.3	5 ft	12.1
6 ft	12.1	6 ft	12.2	6 ft	12.0
7 ft	12.1	7 ft	12.2	7 ft	11.9
8 ft	12.1	8 ft	12.2	8 ft	11.9
9 ft	12.1	9 ft	12.2	9 ft	11.9
10 ft	12.1	10 ft	12.2	10 ft	11.9
11 ft	12.1	11 ft	12.2	11 ft	11.9

TABLE 20. (Cont.)

Station 16		Station 17		Station 18	
Surface	12.2°C	Surface	12.3°C	Surface	12.5°C
1 ft	12.2	1 ft	12.3	1 ft	12.5
2 ft	12.2	2 ft	12.3	2 ft	12.5
3 ft	12.2	3 ft	12.3	3 ft	12.5
4 ft	12.2	4 ft	12.3	4 ft	12.5
5 ft	12.2	5 ft	12.3	5 ft	12.5
6 ft	12.0	6 ft	12.2	6 ft	12.3
7 ft	12.0	7 ft	12.2	7 ft	12.3
8 ft	11.9	8 ft	12.2	8 ft	12.3
9 ft	11.9	9 ft	12.2	9 ft	12.3
10 ft	11.9	10 ft	12.2	10 ft	12.3
11 ft	11.9	11 ft	12.2	11 ft	12.3

Station 19		Station 20		Station 21	
Surface	12.8°C	Surface	12.2°C	Surface	12.2°C
1 ft	12.5	1 ft	12.2	1 ft	12.2
2 ft	12.5	2 ft	12.2	2 ft	12.2
3 ft	12.5	3 ft	12.2	3 ft	12.2
4 ft	12.5	4 ft	12.2	4 ft	12.2
5 ft	12.5	5 ft	12.2	5 ft	12.2
6 ft	12.5	6 ft	12.2	6 ft	11.9
7 ft	12.5	7 ft	12.2	7 ft	11.9
8 ft	12.5	8 ft	12.2	8 ft	11.9
9 ft	12.5	9 ft	12.2	9 ft	11.9
10 ft	12.5	10 ft	12.2	10 ft	11.9
11 ft	12.5	11 ft	12.2	11 ft	11.9
12 ft	12.3	12 ft	12.1	12 ft	11.9
13 ft	12.3	13 ft	12.1	13 ft	11.9
14 ft	12.3	14 ft	12.1	14 ft	11.9
15 ft	11.3	15 ft	12.1	15 ft	11.9
16 ft	11.3	16 ft	12.1	16 ft	11.9
17 ft	11.3	17 ft	12.1	17 ft	11.9

TABLE 20. (Cont.)

Station 22

Surface	12.0°C
1 ft	12.0
2 ft	12.0
3 ft	12.0
4 ft	12.0
5 ft	12.0
6 ft	12.0
7 ft	12.0
8 ft	12.0
9 ft	12.0
10 ft	12.0
11 ft	12.0

Station 23

Surface	12.1°C
1 ft	12.1
2 ft	12.1
3 ft	12.1
4 ft	12.1
5 ft	12.1
6 ft	12.1
7 ft	12.1
8 ft	12.1
9 ft	12.1
10 ft	12.1
11 ft	12.1
12 ft	12.0
13 ft	12.0
14 ft	12.0
15 ft	12.0
16 ft	12.0
17 ft	12.0

Station 24

Surface	12.1°C
1 ft	12.1
2 ft	12.1
3 ft	12.1
4 ft	12.1
5 ft	12.1
6 ft	12.1
7 ft	12.1
8 ft	12.1

Station 25

Surface	12.3°C
1 ft	12.3
2 ft	12.3
3 ft	12.3
4 ft	12.3
5 ft	12.3
6 ft	12.2
7 ft	12.2
8 ft	12.2
9 ft	12.2
10 ft	12.2
11 ft	12.2
12 ft	12.2
13 ft	12.2
14 ft	12.2

Station 26

Surface	12.2°C
1 ft	12.2
2 ft	12.2
3 ft	12.2
4 ft	12.2
5 ft	12.2
6 ft	12.2
7 ft	12.2
8 ft	12.2
9 ft	12.2
10 ft	12.2
11 ft	12.2

each 0.1°, though we are aware of the weakness involved in estimating tenths of a degree from the telethermometer dial. If we take plus-or-minus 0.1° as the uncertainty of our dial readings and consider as real only variations of 0.3°, the main features of the section still come through, but with loss of detail (compare the section if only 12.7, 12.4, 12.1, and 11.8° had been plotted with the section that would have been given by 12.6, 12.3, and 12.0°).

In the bottom of the vertical temperature profile of Station 9 the temperature changed abruptly from 12.7° to 12.5°. It is possible that the ship drifted out of the rising column of warmest water while on the station, but in so doing it seems impossible that, with readings spaced at one foot, it could have missed getting at least one reading of 12.6°; we have consequently considered that the alongshore subsurface current had bent the rising column of warmest water out of the station vertical between the 5-foot and 6-foot readings, and the section has been drawn accordingly.

It appears that a submerged outfall with diffusers does indeed entrain substantial amounts of adjoining water on all its faces and that the horizontal and vertical extent of its effect is minimal.

In Station 19 at the far end of the plume there was a very shallow lens of water from 12.6 to 12.8° floating on the surface in the upper foot of water.

Under the southeast wind of the day there was lakeward movement of warmer surface water, with upwelling of colder subsurface water along the shore. The substantial subsurface depth of temperature 12.5° at Station 19 is taken to be offshore displacement of warm surface water by the wind, not as any effect of the DuPont plume. Inshore temperatures of less than 12.0° are indications of upwelling of subsurface water.

There is no evidence that the outfall was discharging intermittently on 23 October. The vertical section along the plume may have missed a central part of the plume, but if so there is nothing among the data to show where a

missed central plume-part might have been. Instead, it appears most likely that the dilution and cooling processes acting on the plume were not steady, and that the small lens of warm water at Station 19 owed its existence to having passed along the plume axis during a temporary slackening of the dilution and cooling processes, while the length of surface temperatures less than 12.4° represented a return to full (or extra) strength of these processes.

On 4 November 1970, under north wind, a second survey of the DuPont plume was carried out. The wind was from the north at 10-14 mph with a very choppy seas of 1-2 feet height. Air temperature was 5°C.

This day there was, again, upwelling along the shore of colder subsurface water and blowing of warmer surface water away from shore.

Surface temperature on this day was measured by a thermistor suspended from the ship's bowsprit and trailing in undisturbed water ahead of the ship. The temperature field is given in Figure 14.

The total observable effects of the DuPont plume were two small isolated "bubbles" of the 11.4° and 11.1° surface isotherms. These bubbles of the 11.4° and 11.1° isotherms reached downcurrent in the direction shown by a plastic bag full of outfall water which was released at the outfall and retrieved 35 minutes later. The drift of the bag is shown in Figure 14. The bubbles of 11.1° and 11.4° were isolated between the 10.8° and 11.1° isotherms of the alongshore and slightly offshore current and extended downcurrent only a small distance (3/8 mile).

Attempts at vertical temperature profiles were inconclusive and lost in the lake-to-shore gradient of temperature.

Again, the DuPont submerged outfall with diffusers appears to be an efficient system.

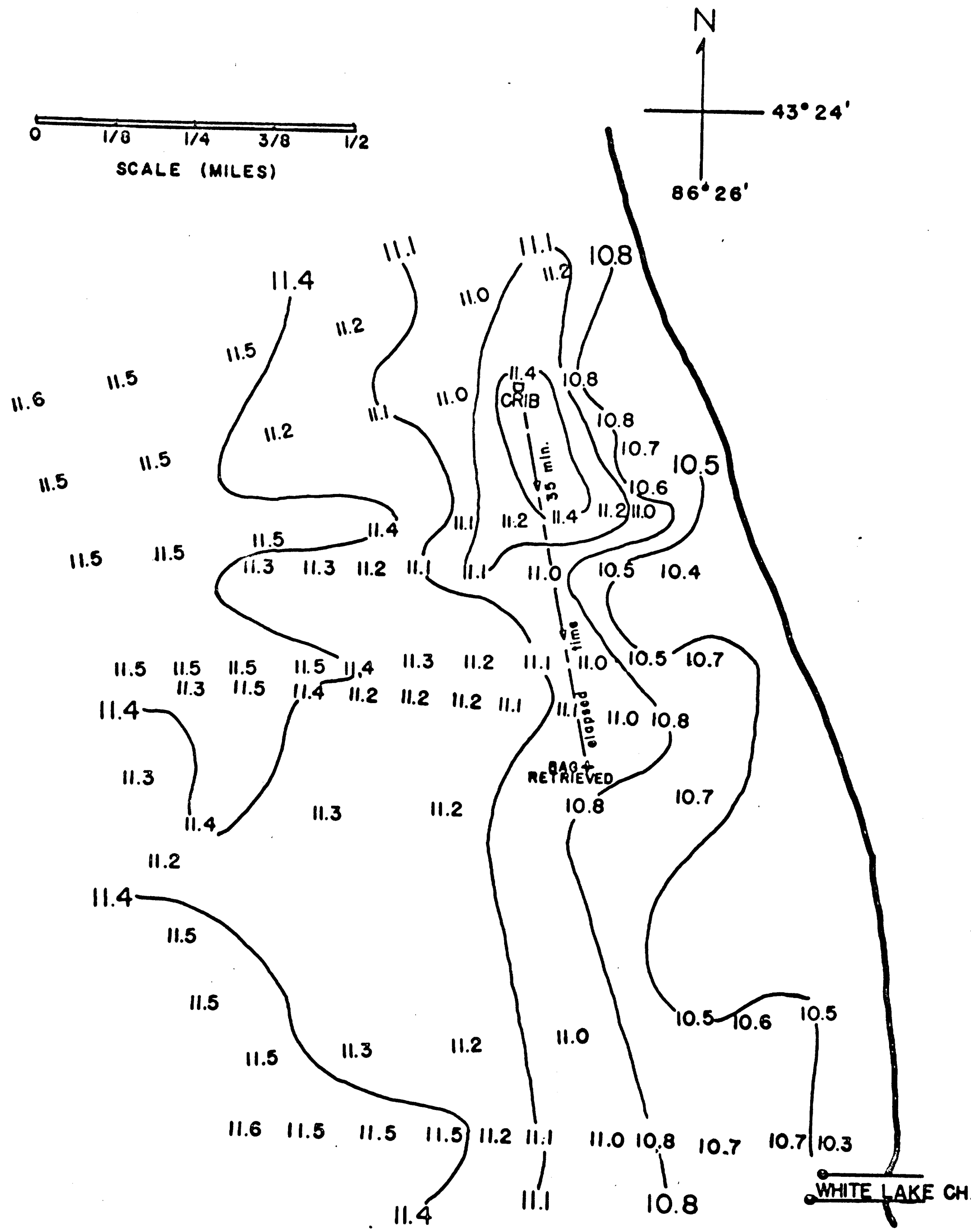

FIG. 14. Horizontal temperature distribution, surface temperature (trail) in °C. November 4, 1970.

Direct Measurements of Thermal Plume Duration. During the development and testing of the bagged-water technique, bags of water were released at plant outfall mouths and allowed to drift down the plume until ambient lake temperature was reached. The bags were nearly filled with water and floated low in the water; we could detect no evidence of wind pushing them out of the plume.

The following summary gives the duration of drift from outfall mouth to points where the surrounding lake water was of ambient temperature.

Place & Date	Type of plant	Load and flow	Wind condition	Drift duration
Bailly 20V170	Generating	522,500 kw 150,000 gpm	SSE 2-8 kn	30 min 28 min
	7°C excess temperature			
Bailly 17X70	Generating	153,600 kw 150,000 gpm	SW 10-14 kn	1h 22 min
Michigan City 17X70	Generating	88,000 kw 70,000 gpm	SW 4-5 kn	1h 04 min
	6°C excess temperature			
Montague	Chemical	7,500 gpm	N 10-14 mph	35* min

* Bag was well out into ambient temperature by this time.

The short durations of the bag drifts were unexpected. They indicate that, even in larger plumes, the duration of the excess heat is probably too brief to trigger excess algal blooms.

C. THE ICE BARRIER AT THE COOK PLANT SITE

During the winters of 1969-70 and 1970-71 a commercial photographer has been employed by Indiana and Michigan Electric Company to photograph lake ice conditions in front of the Cook Plant site on approximately a weekly basis.

This photographic record has been supplemented by overflights by both our Dr. O'Hara and by the Company's photographer.

In addition, Dr. O'Hara and Mr. Jon Barnes of Indiana and Michigan Electric have conducted surveys of the ice barrier on foot.

From the total record of these activities it has been possible to follow the development of the ice barrier, to gain some insight into its nature and behavior during its maturity, and to follow its demise during the spring breakup.

These studies will be pursued through the 1971 breakup and be covered in a report on Winter Operations.

D. EFFECTS OF EXISTING THERMAL DISCHARGES ON LOCAL ICE BARRIERS

In February Dr. O'Hara overflew the Lake Michigan outfalls from Big Rock to and including Bailly Station at Burns Harbor. The results will be included in the report on Winter Operations. In March Mr. William Yocum investigated shore ice at Campbell Plant and Michigan City. His results will also be included in the winter report.

E. EFFECTS OF RADIOACTIVE WASTES IN THE AQUATIC ENVIRONMENT

E.1 Gamma Scan of Bottom Sediments

This section of the work involves the development and use of a mobile underwater device for measuring, in place, the gamma radiation of the lake bottom. The device was developed by Dr. Phillip A. Plato and Mr. Dale E. Gelskey under the supervision of Prof. G. Hoyt Whipple, all of the Radiological Health Group of the Department of Environmental and Industrial Health, the University of Michigan.

The developmental and testing programs have been carried out under a grant from American Electric Power Service Corporation directly to Prof. Whipple. The underwater gamma probe was envisioned for use in pre- and post-operational surveys of the Cook Plant area.

The development and testing have been completed, and one survey of the Cook Plant area has been carried out. A final report to AEPSC was submitted in October 1970.

Since the final report, Dr. Plato and Mr. Gelskey have refined the results and prepared a paper for presentation to the Annual Meeting of the Instrument Society of America in New York City, 17 May 1971. Their paper is here presented in its entirety, with the permission of the authors (Appendix A).

The paper indicates the presence of two "hot spots" and one "cool spot" in the lake sediments near the Cook Plant site. We believe that these spots should be completely defined during the preoperational surveys.

Not knowing of these results at the time, our present contract with AEPSC does not contain funds for work with the gamma probe. We have encouraged Dr. Plato and Mr. Gelskey to apply to AEPSC for the necessary limited funds.

E.2 The Most Sensitive Organism for Concentration of Radwastes

A doctoral thesis by Charles C. Kidd, which constitutes Part VI of our report series, shows that the amphipod, *Pontoporeia affinis*, is a substantial concentrator of manganese-54 and zinc-65. Whether there are other or more active concentrators of radioisotopes among the benthic community has yet to be determined. Kidd's work with Pontoporeia was influenced by: 1) this organism is an important fish-food; and 2) techniques for the laboratory maintenance of benthos had, at that time, extended only to this organism. Since Kidd's work began it has been shown that the same maintenance technique suffices for the deep-water amphipod, *Mysis relicta*, also a fish-food of some importance.

It now appears that the techniques which have maintained Pontoporeia and Mysis in the laboratory are sufficient for the maintenance of most, if not all, of the organisms of the benthic community.

We will be starting, in April, controlled laboratory experiments in which the whole macroorganism benthic community of the Cook Plant area will be maintained in the presence of, and absence of, radioactive isotopes for the purpose of determining whether there is in the community any organism more sensitive to (a better concentrator of) radioactive isotopes than Pontoporeia is of Zn-65.

With our present knowledge of the distribution of the benthos off the Cook Plant, it is evident that substantial quantities of macrobenthic organisms can be collected and transported alive, with their native sediment, to the Ann Arbor laboratory.

We expect to be able to collect, transport, and maintain quantities of Pontoporeia, Mysis, Sphaeriids, Tendipedids and Oligochaetes.

The radioisotopes to which these organisms will be exposed are expected to be (not in order of interest or importance): tellurium, barium, cerium, cesium, strontium, manganese, zinc, iron, iodine, mercury, antimony, and chromium.

The search for the most sensitive organism will be concentrated in the benthic community, for these organisms are stay-at-homes compared to the water-borne and drifting phytoplankton, the weakly-swimming and drifting zooplankton, and the migratory fishes. The periphyton (attached algae) and macrophyton (rooted aquatic plants) are also stay-at-homes, but neither is a demonstrated part of the local biota on the wave-beaten and shifting sand bottom of the immediate Cook Plant area.

E.3 Study of Lake Michigan's Present Radioactivity Content

We consider that this section of the work has been finished. We regard the very substantial treatment of this subject by Golden, Plato, and Whipple in Chapter A of "Lake Michigan Environmental Survey" (Special Report No. 49 of the Great Lakes Research Division of The University of Michigan, November 1970) as being definitive for some years to come.

In view of this, we propose to drop this subheading from the format of subsequent reports.

APPENDIX A

THE USE OF FIELD INSTRUMENTS IN THE OPERATION OF ENVIRONMENTAL SURVEYS AROUND NUCLEAR POWER PLANTS

by

Phillip Plato
Dale E. Gelskey

The University of Michigan
Ann Arbor, Michigan

Paper for oral presentation and publication in the Proceedings of the Annual Meeting, Instrument Society of America, New York City, May 17, 1971.

ABSTRACT

The conventional procedure for following the movement of radioactive wastes released into the environment by nuclear power plants involves collecting samples, transporting the samples to the laboratory, preparing the samples for counting, counting the samples for radioactivity, and analyzing the data. A long lag time exists from the time the sample is collected until the analysis is complete.

A device has been built which permits the quantitative identifications of radionuclides present in undisturbed sediments of lakes and streams. The device has been used on sediments around several nuclear power plants. Field measurements also have been made on the soil of a dairy farm near a nuclear power plant. The device permits environmental measurements to be made over larger areas and with better sensitivity than is possible using conventional sampling methods.

INTRODUCTION

Nuclear energy provides man with an energy source for generating electricity. At present there are 16 nuclear power plants operating in the United States and 82 additional plants under construction or being planned by 1976 (1). The operation of nuclear power plants results in the release of small quantities of radioactive wastes into the environment. Man can be exposed to these wastes through air, water, or food supplies. Continuous surveillance of these environmental pathways to man is essential to assure that the risk from the radiation exposures are kept at a minimum.

Since water is one of the most direct pathways from plant to man, interest is placed on analyzing the components of the marine ecosystem for radionuclides released by a nuclear facility. Sediment, as part of every marine environment, constitutes a reservoir for radioactive materials by virtue of its chemical and physical characteristics; thus it is of particular interest to monitor this phase of the nuclear plant's environment.

The conventional procedure for making radiological measurements of sediment involves collecting disturbed grab samples using some type of dredging device, transporting the samples to a laboratory for oven drying, and obtaining a gamma ray spectrum for each sediment sample using a multichannel pulse height

analyzer. The spectra are then analyzed for radionuclides present in the sample. This procedure can be simplified by combining the collection and analysis steps using the underwater gamma probe developed under a grant from the American Electric Power Service Corporation to The University of Michigan (2). The probe travels above the bottom sediments and measures quantitatively and qualitatively the radioactive content of the sediment. The radiation detector is housed in a high floatation tire measuring 1 meter in diameter and 1.5 meters wide, which rolls across the lake bottom with minimal disturbance to the sediment. The tire, containing the detector, has been used successfully on very rocky bottoms, on bottoms consisting of hard packed sand, silt, clay, and on loosely packed bottoms. The detector is connected by an electrical cable to the analyzing equipment located aboard a boat.

INSTRUMENTATION

Figure 1 shows a block diagram of the system designed for *in situ* gamma radiation measurements of sediment. The detector consists of a right circular cylindrical sodium iodide crystal 10 cm thick by 12 cm in diameter. The crystal is connected optically to a 12 cm diameter photomultiplier tube. The phototube with an average anode current of 2 mA drives the signal through 500 m of coaxial cable and provides adequate pulse height for analysis across a 52 ohm load resistor, so that no signal preamplification is required at the submerged end of the

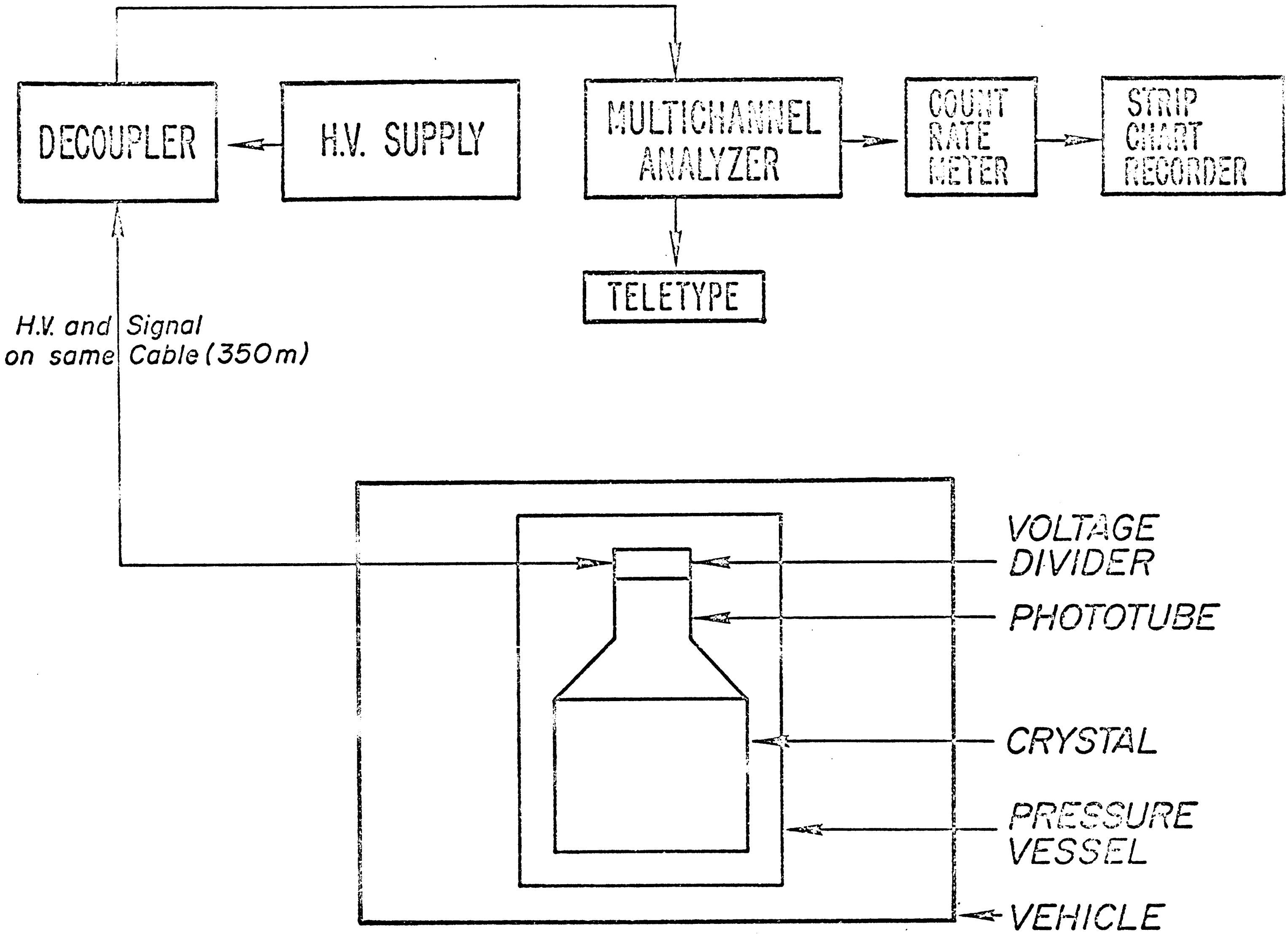

Figure 1

BLOCK DIAGRAM OF AMPHIBIOUS GAMMA RADIATION DETECTION SYSTEM

system. Figure 2 shows the detector circuit (3) which allows a minimal number of electrical components to be located underwater. An aluminum pressure vessel is used to protect the crystal, phototube, and voltage divider against water, pressure and thermal and physical shock. The vessel is designed to withstand pressures encountered in water depths up to 350 meters.

The large rubber tire, used to support and transport the detector above the sediment, is towed by a boat. Figure 3 demonstrates the method used to position the aluminum pressure vessel inside the tire. The vessel is mounted pendulously to the axle which connects the tire's two steel side rims. As the tire rotates about the stationary axle, the detector located inside remains in a vertical attitude. The co-axial cable which transmits signals from the submerged detector to the analyzing equipment enters the tire through a hollow axle and connects to the detector. The semicircular tow bar defects the tire around obstacles protruding upward from the bottom. Drain plugs located in each of the tire's rims are removed allowing water to fill the tire and are replaced before the tire is lowered to the sediment.

The signal pulse, transmitted on the same cable which supplies the high voltage to the detector, is stripped from the high voltage by a decoupler (Figure 1) located on the boat. Gamma ray produced pulses from the detector are recorded in two ways: a 256-channel pulse height analyzer sorts the pulses into a gamma ray spectrum; and a count rate meter coupled to a strip

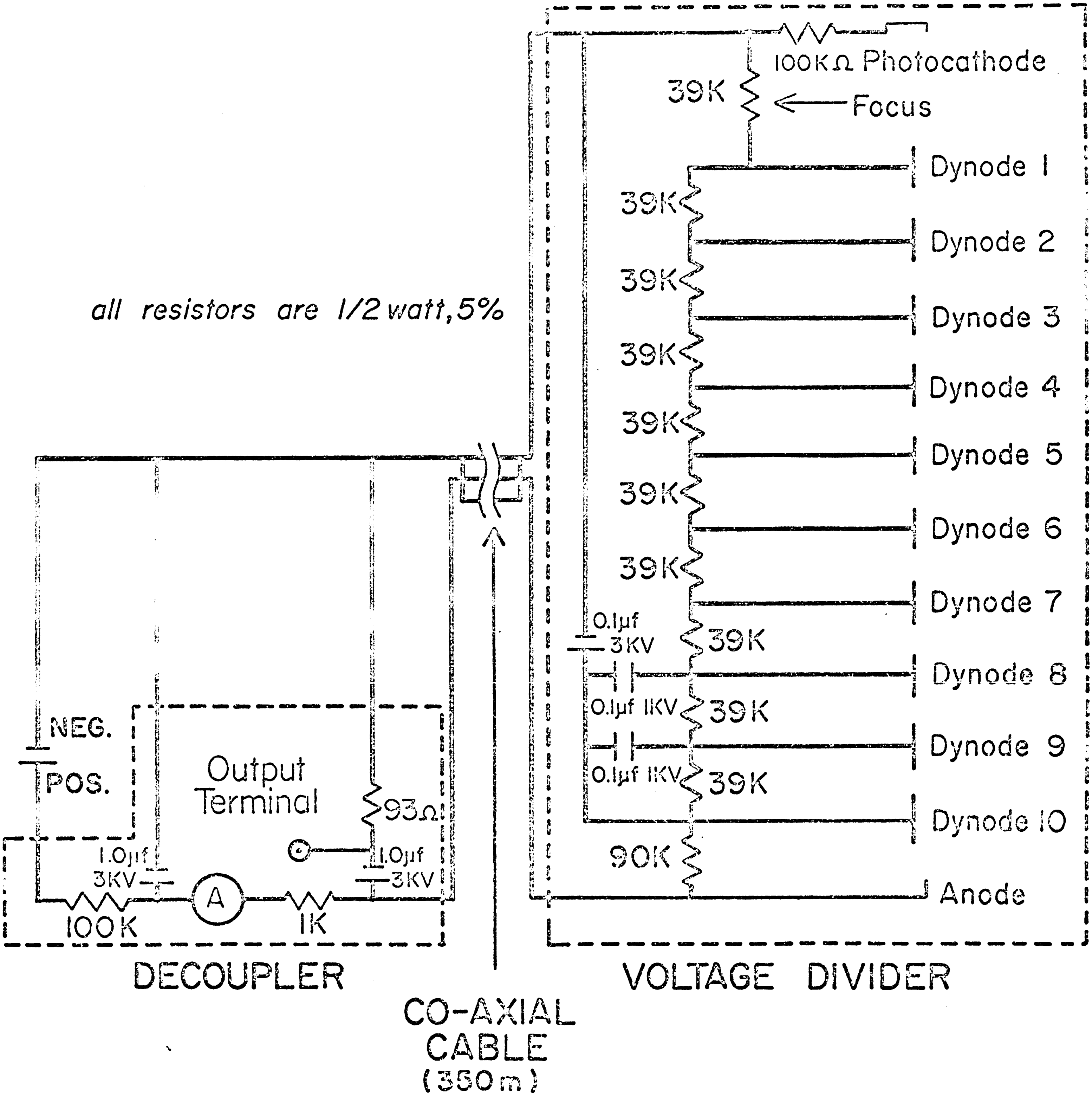

Figure 2

RADIATION DETECTOR
CIRCUIT DIAGRAM

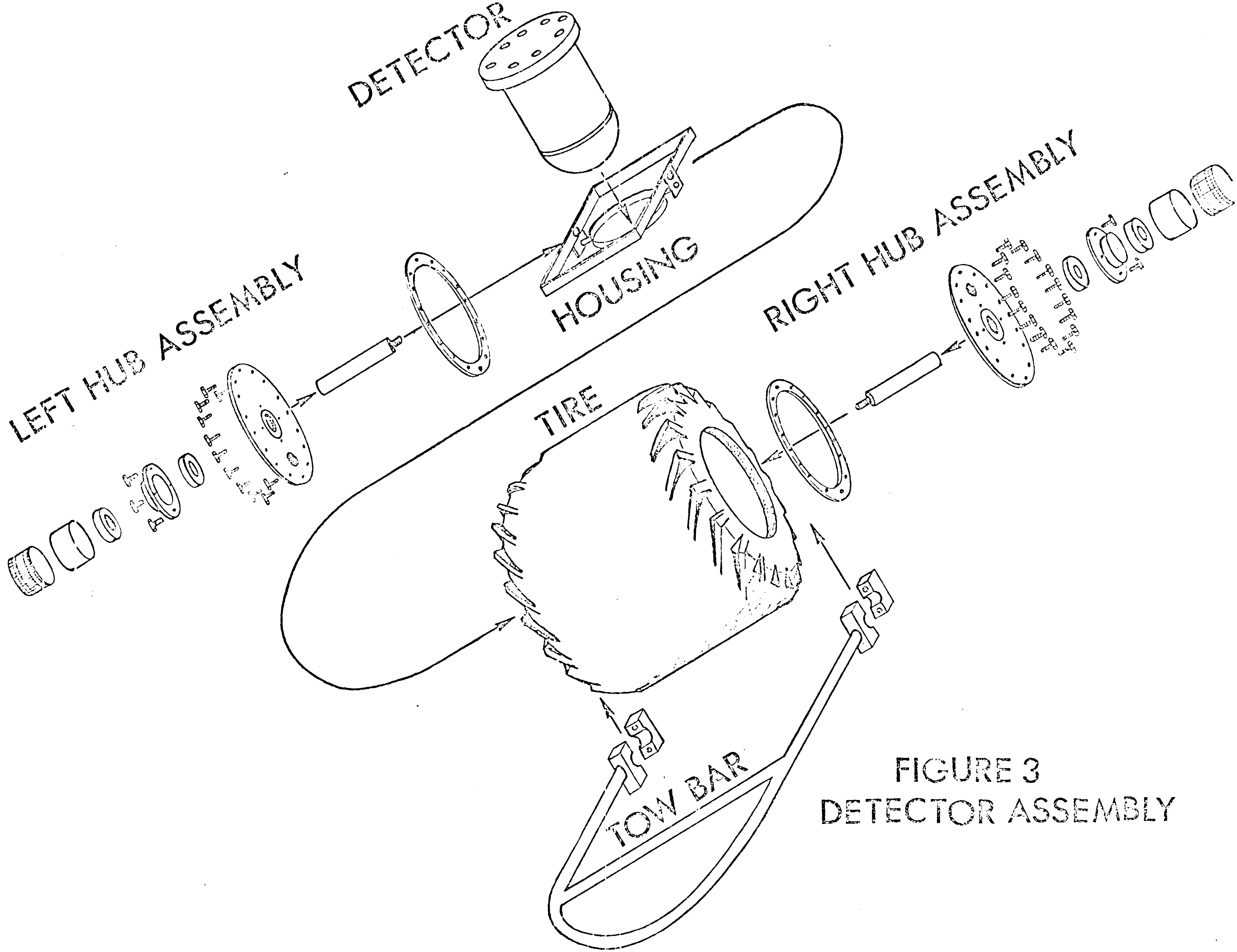

FIGURE 3
DETECTOR ASSEMBLY

chart recorder records the gross gamma rays interacting with the crystal. A low level energy discriminator filters out low energy noise pulses allowing the count rate meter to be made sensitive to only small changes in high energy gamma ray produced pulses. A Teletype unit records each gamma spectrum on paper and punched paper tape. The data on the tape are transferred easily to magnetic tape for computer manipulation. The operator observes both the strip chart record and gamma ray spectrum displayed on the oscilloscope to detect changes in the gamma ray activity as the detector travels over the sediment.

DATA ANALYSIS

The underwater gamma radiation probe is an effective tool for determining which radionuclides are present in bottom sediments. Since the detector is moving while radiation measurements are made, areas of high and low radioactivity can be mapped with far greater ease than is possible by taking conventional grab samples. It was decided that quantitative, as well as qualitative, measurements of radionuclides present in bottom sediments were desirable for work around nuclear power plants. Thus, a quantitative calibration was required.

The underwater probe was calibrated in the laboratory using a 12-foot diameter plastic swimming pool. Sand was distributed uniformly on the bottom of the pool to simulate natural sediment.

The effective area over which the detector can measure gamma radiation was determined by coiling Tygon tubing to form a flat plane on the surface of the sand with the detector mounted inside the rubber tire above the Tygon tubing. A solution of cesium-137 was pumped through the Tygon tubing and the activity of the cesium-137 was recorded. The diameter of the coiled Tygon tubing was increased until the activity measured did not increase with an increase in coil diameter. It was determined that a coil diameter greater than 70 cm contributed no additional counts from the cesium-137. Thus, 70 cm was taken to be the diameter of the effective area over which the detector is sensitive.

The coiled Tygon tubing was used to obtain standard reference spectra by pumping known activities of various radionuclides through the tubing. Reference spectra were obtained for Cs-137, Zn-65, Mn-54, Co-58, Co-60, K-40, and Ra-226. The library of reference spectra are used to analyze quantitatively gamma ray spectra obtained in the field.

A spectrum analysis computer program which uses the least squares method has been developed by J.I. Trombka of the Goddard Space Flight Center (4). The computer program was revised substantially for counting environmental samples and named NASA after its original sponsor.

The NASA program constructs a spectrum from the library reference spectra to match a spectrum taken in the field. The final results given by the NASA program for each sample consists of a graph of the field spectrum and one data sheet which con-

tains the activities of each of the radionuclides present in the sample spectrum. The graph of the field spectrum is used to detect the presence of radioisotopes for which the NASA program was not looking.

The data sheet includes two error values for each field spectrum analyzed. The chi square value is a measure of how well the entire calculated spectrum matched the field spectrum. The amount of each radionuclide predicted to be in the field spectrum has associated with it a standard deviation expressed as a percent of the predicted activity. The two error values together with the graph of the field spectrum are used to decide the validity of the predicted activities for the given field spectrum.

Field work around the Big Rock Point Nuclear Power Plant has established a minimum detectable activity for cesium-137 of 0.02 microcuries per square meter. Minimum detectable activities for other radionuclides will vary depending on gamma ray energies and abundances.

APPLICATIONS

Measurements of radionuclides present in bottom sediment near the Palisades and the Donald C. Cook Nuclear Power Plants were made with the underwater gamma probe during the Fall of 1970. Both plants are located on the shore of Lake Michigan near Benton Harbor, Michigan. The Palisades Plant is scheduled to become operational during 1971, and the Cook Plant is still under construction. Thus, both surveys provided preoperational data for future reference.

Four passes were made at each plant with the underwater probe. The passes ran parallel to the shoreline from four miles north to four miles south of each plant. The passes were made at distances of 3/8, 3/4, 1 1/2, and 3 miles from shore. Figure 4 shows the ship's course during the survey of the Donald C. Cook Plant.

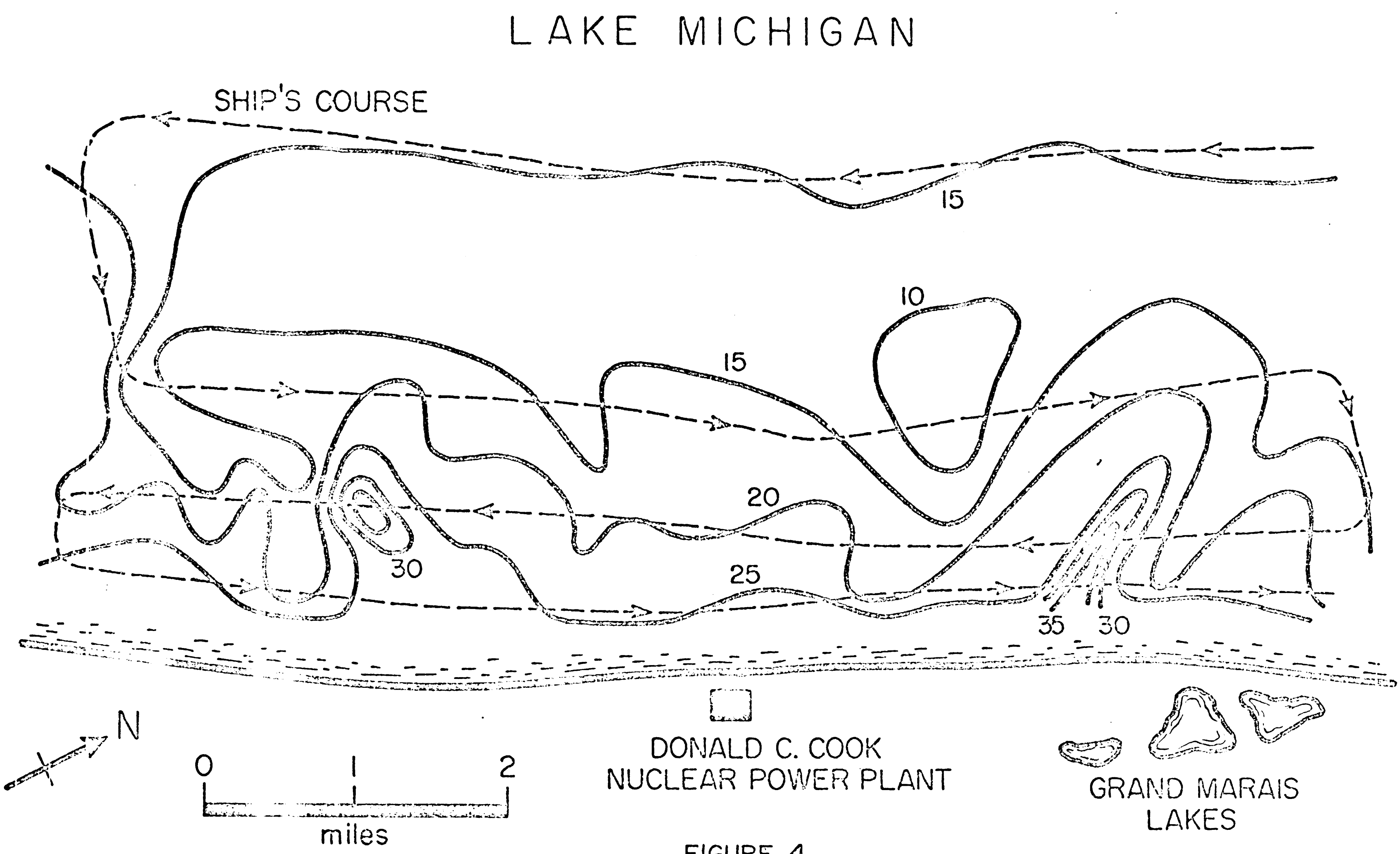

FIGURE 4

CONTOUR LINES SHOWING GROSS GAMMA RADIATION (counts per second) IN LAKE MICHIGAN SEDIMENT DURING CONSTRUCTION OF THE DONALD C. COOK POWER PLANT, SEPTEMBER 1970

The parallel passes made at the Palisades and Cook Plants permitted interpolations to be made for gross gamma activity between the passes. Contour lines drawn between the passes show the areas of particular radiological interest.

Gross gamma activity is recorded on a strip chart recorder throughout a survey. Figure 4 shows the contour lines drawn between the passes made near the Donald C. Cook Plant. Ridges of relatively high gross gamma activity can be seen near the shoreline about two miles north and about two miles south of the plant. An area of relatively low activity can be seen about two miles off shore from the plant.

The only radionuclides present in the gamma ray spectra taken near the Palisades and Cook Plants were naturally occurring potassium-40 and radium-226. Figure 5 is an attempt to construct contour lines of potassium-40 in the sediments near the Donald C. Cook Plant. The same areas of relatively high and low activities observed in Figure 4 are apparent in Figure 5.

CONCLUSIONS

An underwater gamma radiation probe was constructed to provide qualitative and quantitative measurements while traveling over bottom sediments. The underwater probe was used at two nuclear power plant sites to determine preoperational levels of radioactivity present in the sediments near the plants. Contour lines of gross gamma activity and the naturally occurring radionuclide potassium-40 were drawn to identify areas of relatively high and low activities.

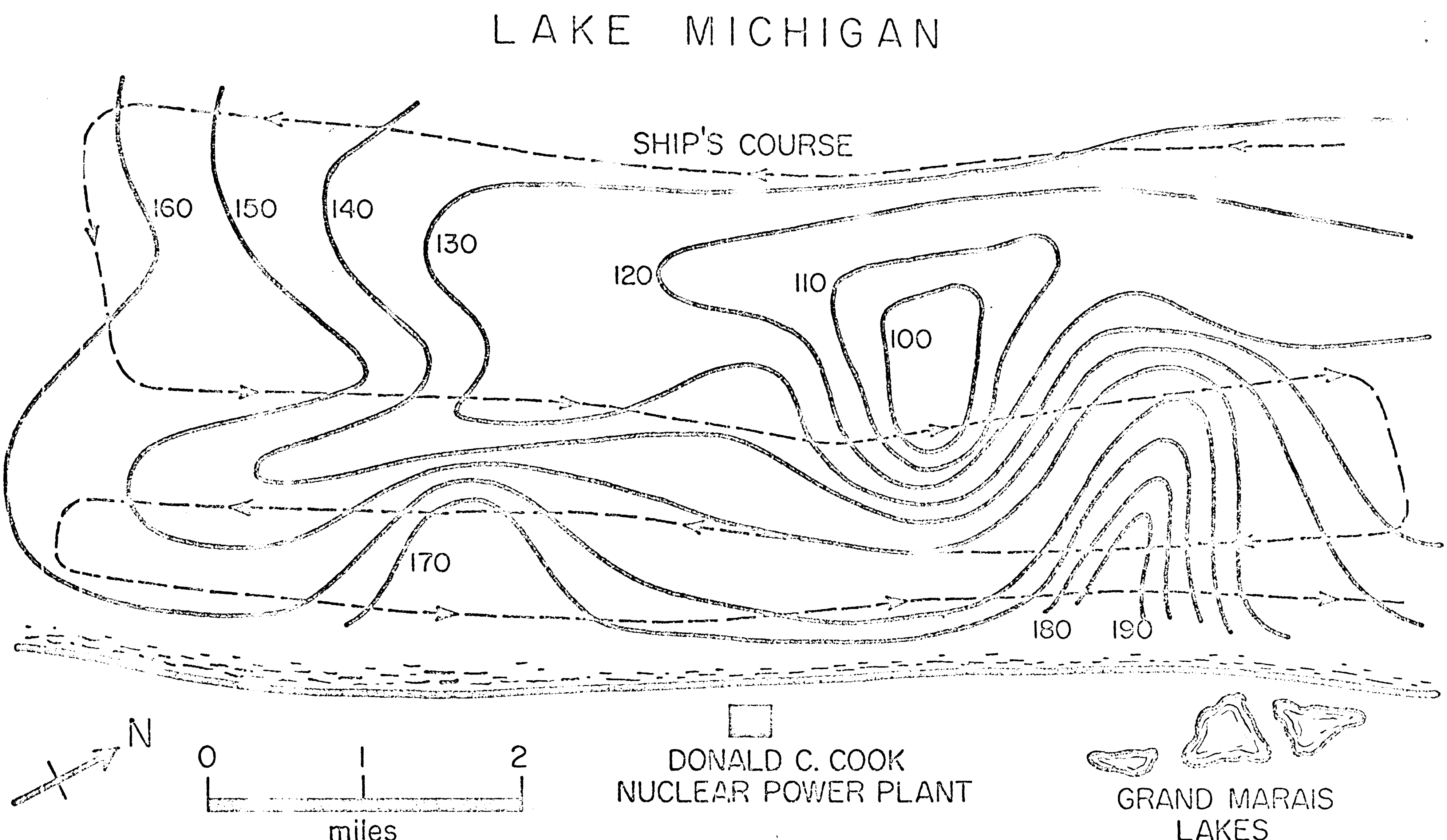

FIGURE 5

CONTOUR LINES SHOWING ACTIVITY OF NATURALLY OCCURING POTASSIUM-40 (microcuries per square meter) IN LAKE MICHIGAN SEDIMENT DURING CONSTRUCTION OF THE DONALD C. COOK NUCLEAR POWER PLANT, SEPTEMBER 1970

REFERENCES

(1) Environmental Health Problems, U. S. Dept. of Health, Education, and Welfare, Public Health Service, Environmental Health Service, GPO: 1970 0-380-961.

(2) Plato, P. A., Gelskey, D. E., and Whipple, G. H., Underwater Gamma Radiation Detection System, final report submitted to the American Electric Power Service Corporation, New York, October, 1970.

(3) Riel, G. K., U. S. Naval Ordnance Laboratory, White Oak, Silver Spring, Md.

(4) Trombka, J. I., and Schmadebeck, R. L., A Numerical Least Squares Method for Resolving Complex Pulse Height Spectra, National Aeronautics and Space Administration, Office of Technology Utilization, Washington, 1968.